SEDAR7

Southeast Data, Assessment, and Review

Stock Assessment Report
of
SEDAR 7

Gulf of Mexico Red Snapper

SEDAR7
Assessment Report I

SECTION III. Stock Assessment Workshop Report

Introduction

Two assessment worskhops were conducted during SEDAR 7. The first convened at the SEFSC Laboratory in Miami FL from August 16-20, 2004. The second convened at the Wyndham Grand Bay in Coconut Grove, FL from December 14 – 17, 2004.

Terms of Reference

1. Select several appropriate modeling approaches based on: 1) available data sources, 2) parameters and values required to manage the stock, and 3) recommendations of the Data Workshop – especially including consideration of possible eastern and western stock units; develop and solve population models incorporating the most recent scientifically sound data.
2. Select a preferred model approach that will be used to provide estimates of population parameters and stock status; provide complete justification for the selected model as well as a review of those methods pursued but ultimately rejected as a preferred approach.
3. Provide measures of model performance, reliability, and goodness of fit.
4. Estimate values for and provide tables of relevant stock parameters (abundance, biomass, fishery selectivity, stock-recruitment relationship, etc; include values by age and year where appropriate).
5. Consider sources of uncertainty related to input data, modeling approach, and model configuration. Provide appropoRiate and representative measures of precision for stock parameter estimates.
6. Prepare sensitivity runs or consider other modeling approaches to examine the reliability of input data sources.
7. Provide Yield-per-Recruit and Stock-Recruitment analyses.
8. Provide complete SFA criteria: evaluate existing SFA benchmarks, estimate values for alternative SFA benchmarks if appropriate, and estimate SFA benchmarks (MSY, Fmsy, Bmsy, MSST, and MFMT) if not previously estimated; develop stock control rules.
9. Provide declarations of stock status relative to SFA benchmarks: MSY, Fmsy, Bmsy, MSST, MFMT (or their proxies if appropriate).
10. Estimate the Allowable Biological Catch (ABC) for each stock if appropriate.
11. Estimate probable future stock conditions and develop rebuilding schedules if warranted; include estimates of generation time. Calculate rebuilding analyses under the following future exploitation possibilities: F=0, F=current, F=current*0.25, F=current*0.5, F=current*0.75.
12. Evaluate the impacts of current management actions, with emphasis on determining progress toward stated management goals.
13. Provide recommendations for future research and data collection (field and assessment); be specific possible in describing sampling design and recommended sampling intensity.
14. Provide thorough justification for any deviations from recommendations of the Data Workshop or subsequent modification of data sources provided by the Data Workshop.
15. Fully and completely document all activities in writing:

    Draft Section III of the SEDAR Stock Assessment Report;

        Provide required tables of estimated values

Prepare a first draft of the Advisory Report based on the Assessment Workshop's recommended base assessment run for consideration by the Review Panel

Report Completion Schedule:

Draft of all text to SEDAR Secretary for formatting: 2 wks, September 8 2004.
(Will be sent to participants for content review during formatting)
Content Comments Due: 1 week, September 15, 2004
Final Draft to Panel for review: September 17, 2004
Final Comments to Staff: 1 week, September 24, 2004
Final Report Distributed to Review Panelists: October 1, 2004

List of Participants

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List of Assessment Workshop Working Papers

Document Number	Document Title	Authors
SEDAR7-AW 1	Growth models for red snapper in U.S. Gulf of Mexico waters estimated from landings with minimum size limit restrictions	Diaz, Guillermo A., Clay E. Porch, and Mauricio Ortiz
SEDAR7-AW 2	Allometric relationships of Gulf of Mexico red snapper	Diaz, Guillermo A.
SEDAR7-AW 3	Estimated conversion factors for calibrating MRFSS charterboat landings and effort estimates for the Gulf of Mexico in 1981-1997 with For Hire Survey estimates with application to red snapper landings	Diaz, Guillermo A and Patty Phares
SEDAR7-AW 4	Revised catch rate indices for red snapper (*Lutjanus campechanus*) landed during 1981-2003 by the U.S. Gulf of Mexico recreational fishery - REVISED	Cass-Calay, Shannon L.
SEDAR7-AW 5	Batch-fecundity and maturity estimates for the 2004 assessment of red snapper in the Gulf of Mexico	Porch, Clay E.
SEDAR7-AW 6	An age-structured assessment model for red snapper that allows for multiple stocks, fleets and habitats	Porch, Clay E.
SEDAR7-AW6a	Calculation of relative length frequencies	Brooks, E.N.
SEDAR7-AW 7	Preliminary Trials Estimating M1 from Fall and Summer Trawl Surveys	Brooks, Elizabeth N. and Clay E. Porch
SEDAR7-AW 8	Red Snapper Compensation in the Stock-Recruitment Function and Bycatch Mortality	Powers, J.E. and E.N. Brooks
SEDAR7-AW 9	Standardized catch rates of red snapper (*Lutjanus campechanus*) from the United States commercial handline fishery in the Gulf of Mexico during 1996-2003: additional indices	McCarthy, Kevin J. and Shannon L. Cass-Calay
SEDAR7-AW 10	Not used	
SEDAR7-AW 11	A population dynamics model for Gulf of Mexico red snapper that uses a historically extended catch time series and alternative methods to calculate MSY	McAllister, Murdoch K.
SEDAR7-AW 12	Impact on Yield from Density Dependence of red Snapper Juvenile Life Stages	Gazey, W.J.
SEDAR7-AW 13	Brief Review of Red Snapper Data Workshop Report	McAllister, Murdoch K.
SEDAR7-AW 14	Identifying some approaches to formulating prior probability distributions for natural mortality rates in age zero and age one Gulf of Mexico red snapper	McAllister, Murdoch K.
SEDAR7-AW 15	Estimation of Juvenile M for Red Snapper Based on SEAMAP Survey Data	Nichols, Scott, Gilmore Pellegrin Jr. and G. Walter Ingram
SEDAR7-AW 16	Estimates of Historical Red Snapper Recreational Catch Levels Using US Census Data and Recreational Survey Information	Scott, Gerald P.
SEDAR7-AW 17	Documentation on the Preparation of the Database for the Red Snapper Stock Assessment SEDAR	Poffenberger, John and Stephen C. Turner

	Workshop	
SEDAR7-AW 18 revised	Modeled age composition of Gulf of Mexico Red Snapper 1984-2003	Turner, Stephen C., Elizabeth Brooks, Gerald P. Scott and Guillermo Diaz
SEDAR7-AW 19	Gulf of Mexico Red Snapper Observed Catch at Age	Sladek Nowlis, Josh
SEDAR7-AW 20	Estimating Catch at Age for Red Snapper in the Shrimp Fleet Bycatch	Nichols, Scott

Presented at Assessment Workshop Session 2, December 14 – 17, 2004:

SEDAR7-AW 21	A Summary of the August Assessment Workshop for Red Snapper	Anonymous
SEDAR7-AW 22	The commercial landings of red snapper in the Gulf of Mexico from 1872 to 1962	Porch, Clay E., Stephen C. Turner, and Michael J. Schirripa
SEDAR7-AW 23	Reconstructed time series of shrimp trawl effort in the Gulf of Mexico and the associated bycatch of red snapper from 1948 to 1972	Porch, Clay E. and Steve Turner
SEDAR7-AW 24	Additional information on modeled age composition of red snapper from the Gulf of Mexico 1984-2003	Turner, Stephen C., Elizabeth Brooks, and Guillermo Diaz
SEDAR7-AW 25	Alternative indices of abundance of juvenile red snapper from the Gulf of Mexico from SEAMAP surveys 1972-2003	Turner, Stephen C., and Clay E. Porch
SEDAR7-AW 26	An age-structured stock reduction analysis (SRA) model for the Gulf of Mexico red snapper that accounts for uncertainty in the age of density-dependent natural mortality	McAllister, Murdoch K.
SEDAR7-AW 27	An alternative assessment of the red snapper (*Lutjanus campechanus*) fishery in the U.S. Gulf of Mexico using a spatially-explicit age-structured assessment model: Preliminary results	Porch, Clay E.
SEDAR7-AW 28	Benchmarks and Estimated Status from a 1-fleet VPA projection for Red snapper (*Lutjanus campechanus*)	Brooks, Elizabeth N. and Steve Turner
SEDAR7-AW 29	VPA Evaluation of Projected SPR resulting from TAC and Bycatch Reduction for Red snapper (*Lutjanus campechanus*) in the Gulf of Mexico	Brooks, Elizabeth N. and Steve Turner
SEDAR7-AW 30	Assessments of Gulf of Mexico red snapper during 1984-2003 using a Gulfwide implementation of ASAP, including continuity cases	Cass-Calay, Shannon L. and Guillermo A. Diaz
SEDAR7-AW 31	Assessments of Gulf of Mexico red snapper during 1962-2003 using a Gulfwide implementation of an age-structured-assessment-program (ASAP)	Cass-Calay, Shannon L., Guillermo A. Diaz, and Joshua Sladek Nowlis

SEDAR7-AW 32	Draft: Bootstrapping a Gulfwide implementation of an age-structured-assessment-procedure (ASAP) for red snapper (*Lutjanus campechanus*) from 1962 to 2003	Sladek Nowlis, Joshua and Shannon L. Cass-Calay
SEDAR7-AW 33	Summary of all model runs and control rule plots	Brooks, Elizabeth N.
SEDAR7-AW 34	Assessments of red snapper stocks in the eastern and western Gulf of Mexico using an age-structured-assessment-procedure (ASAP)	Cass-Calay, Shannon L. and Mauricio Ortiz

After the December Asssessment Workshop some papers were substantially revised, one was newly developed and another paper was not formally presented to the workshop. These papers are listed below as RW (review workshop) documents.

SEDAR7-RW 1	Application of the age-structured assessment model CATCHEM to the U.S. Gulf of Mexico red snapper fishery since 1962	Porch, Clay E.
SEDAR7-RW 2	Revised Assessments of Gulf of Mexico red snapper during 1984-2003 using a Gulfwide implementation of ASAP	Cass-Calay, Shannon L. andGuillermo A. Diaz
SEDAR7-RW 3	Revised Assessments of Gulf of Mexico red snapper during 1962-2003 using a Gulfwide implementation of an age-structured-assessment-program (ASAP)	Cass-Calay, Shannon L., Guillermo A. Diaz, and Joshua Sladek Nowlis
SEDAR7-RW 4	Assessments of red snapper stocks in the eastern and western Gulf of Mexico using an age-structured-assessment-procedure (ASAP). Revised and updated analysis of results presented in SEDAR7-AW-32	Ortiz, Mauricio and Shannon L. Cass-Calay
SEDAR7-RW 5	Revised bootstrapping a Gulfwide implementation of an age-structured-assessment-procedure (ASAP) for red snapper (*Lutjanus campechanus*) from 1962 to 2003	Sladek Nowlis, Joshua and Shannon L. Cass-Calay
SEDAR7-RW 6	An age-structured stock reduction analysis (SRA) model for Gulf of Mexico red snapper that accounts for uncertainty over the ages of density-dependent natural mortality	McAllister, Murdoch K.
SEDAR7-RW 7	Alternative fishery independent larval indices of abundance for red snapper	Hanisko, D., J. Lyczkowski-Shultz, and W. Ingram

List of additional documents and appendices for this report.

Document number	Description
Proceedings document	Annotated proceedings of August and December assessment workshops
Appendix 1	Data inputs
Appendix 2	Overview of projection and assessment results
Appendix 3	Summary table of benchmarks and status all models (excel file)
Appendix 4	ASAP Gulf wide projection results
Appendix 5	ASAP East and West projection results
Appendix 6	VPA projection results
Appendix 7	SRA Results
Appendix 8	Assessment output
Appendix 9	Assessment programs and inputs

Overview Document

Red snapper has been the subject of five stock assessments since 1990, the last in 1999. That history has covered a large range of modeling decisions, what-if's, sensitivities, revisits to the primary data, and major external peer reviews. However, all past assessments have ultimately been limited by the same problem: it has been impossible to determine a convincing relationship between parent stock and subsequent juvenile recruitment. This is not an unusual problem in stock assessment, but the red snapper case has some unique features. After about 20 years of collecting detailed data and perhaps 20-fold variations in year class strength, parent stock size appears to have barely changed.

In recent stock assessment meetings, the problem has usually been discussed in terms of a model parameter called 'steepness,' often abbreviated as *h*. In its common usage, steepness is theoretically bounded by values of 0.2 and 1.0 and represents the number of recruits produced by a parental stock reduced by 80% relative to the number of recruits produced by an unfished parental stock. A high steepness value (*i.e.* approaching 1.0) actually implies that recruitment rates may remain high down to very low levels of parent stock abundance, only then 'steeply' declining. A lower value implies a longer, slower curvature to the relationship -- recruitments will tend to decline as parent stock declines, slowly early in the history of the fishery, then at an increasing rate if parent stocks continues to be reduced.

With red snapper, the assessment scientists have had a dilemma. Twenty years of red snapper data, taken at face value, suggested steepness is very high (above 0.95), higher than most scientists believe possible. Experience with stocks similar to red snapper suggested steepness should be nearer to 0.8 than 1.0. The different values have had important implications for long-term management advice. For red snapper, accepting the high steepness implied more drastic reductions were needed to make management targets within defined time frames, but opened the question of whether the targets were set unnecessarily high. Accepting the lower value implied that current restrictions could be closer to what is needed, that ultimate production might be much higher than ever seen, but that rebuilding could be prolonged.

There have been many advances in information available for the present assessment, but it was expected coming in that spawning stock abundance had still not moved enough since 1999 to improve our knowledge of stock-recruitment. Therefore, a different direction was suggested during the SEDAR process. Considerable effort was devoted to reconstructing a time series of catch estimates going back to the dawn of the fishery as recommended by the Data Workshop. By running the assessment models on this extended, 'ultra-historical' series, we hoped to develop enough contrast in spawning stock and recruitment to define the stock-recruitment relationship.

That effort is now complete. The extended analyses continue to support a very high estimate for steepness. In fact, results are consistent with recent recruitments being amongst the highest they ever have been, despite a spawning stock very depleted by most any standard. However, the 'ultra-historical' series has pinned down virgin stock sizes in such a way that stock status results are no longer as sensitive to steepness as they were in past assessments, at least in the context of the favored model. This is reassuring, but with the caveat that the ultimate productivity of the snapper stock is not a settled issue. Because of that, we urge readers to focus more on short term (5-10 yr) directions of management advice, and how to tend toward a more desired state, without unduly emphasizing specific targets and how to attain them.

Over the last 5 years, the scientific community has produced many major advances in the red snapper information base. Statistical coverage has improved, as has age and length sampling. Fishery independent surveys were expanded, the SEAMAP trap / video survey was resumed, and a new longline survey was initiated. Expanded sample processing led to major improvements in growth and fecundity information, and allowed derivation of SEAMAP larval indices. Analytical advances included improved evaluation of uncertainty, and improved age composition information for shrimp fleet bycatch and for SEAMAP trawl surveys. These in turn led to a better estimate of juvenile M. Large MARFIN research projects strengthened the plausibility of East and West substructure to the stock, provided interesting information on juvenile habitat utilization, and improved the knowledge base on release mortality. In order to accommodate and take advantage of these gains in information, a new assessment model (named CATCHEM) was developed, with much greater generality, better mathematical rigor, and the capability to handle geographic substructure. Although some fundamental uncertainty over stock productivity remains, many other areas of previous concern have been resolved, or at least uncertainty has been substantially reduced. All these advances should benefit future assessments of other stocks as well, as the data collection and analytical advances will largely be applicable.

This report and supporting information are organized in several layers. The discussion in this Overview Report relies largely on the CATCHEM models selected by the Assessment Workshop (AW) as the most appropriate. A write-up of the proceedings of the AW meetings follows as a separate report. During the AW, a number of other models were also used to evaluate the sensitivity to features about the modeling *per se* for which we have uncertainty. These other model are referred to as ASAP (for Age-Structured Assessment Procedure), SRA (for Stock Reduction Analysis), and VPA (for Virtual Population Analysis). Findings from other sensitivity runs are referred to in this Overview Report, and sketched out in the Proceedings Report, but most of the information about these runs has been collected in the Appendices, and in the AW-# working paper series. Of course, the SEDAR process also includes a major document summarizing the recommendations from the Data Workshop (DW), which is included. Electronic versions of documents submitted for consideration by AW and DW are also provided.

A word of warning is warranted concerning interpretation of the MSY benchmarks: In this arena the usage of the term MSY has evolved over the years such that it no longer refers to just a property of the stock, but has now become conditional on selectivity patterns within and among fisheries. Several participants in the AW do not favor this newer usage for the term MSY, feeling that selectivity modifications are more properly treated as part of OY considerations. However, all agree that reporting benchmark evaluations based on different selectivity scenarios provides important insight. Confusion may arise because making different choices about selectivity and benchmark construction leads to some of the biggest differences in statements about stock status in the results. These differences do not imply 'uncertainty' in the same sense that we speak of uncertainty due to imprecise knowledge of catches, or steepness, or M, for example. The "uncertainty" among the different MSY metrics is really an uncertainty about what strategies the Gulf of Mexico Fishery Management Council might consider possible or practical, and how they might choose to allocate among competing users. The biggest issue here is interpretation of the impact of the shrimp fishery. The Council may have the authority to decide what it considers 'bycatch reduction to the extent practical' per National Standard 9, and <u>then</u> consider status of the stock conditional on that decision. Using the term MSY in that context can result in stock status statements that may seem more 'favorable' than the Council is used to seeing for red snapper (although these status findings may be paired with more restrictive advice toward directed fishery futures), while the biological situation is very similar to what has been reported in the past. This usage will work as long as readers understand it, but readers must be 1) careful to recognize what type of benchmarks are being referred to in any instance, 2) understand what each implies about the sorts of management that might be considered, and 3) avoid comparing across benchmarks types using 'better' or 'worse' evaluations of stock status. To aid the reader and to provide a basis for comparing results of the assessment herein with prior assessment results, we have also provided Spawner per Recruit (SPR) metrics. In this way, it is easier to examine the implications of different allocations between fishing sectors on the current and longer-run depletion of spawning stock. Due to the uncertainty over the true underlying stock-recruitment relationship, SPR proxies for MSY benchmarks, which have been used by the Council, may in fact remain the most robust.

Data Issues and Deviations from Data Workshop Recommendations

All the technical papers in the AW-# series were developed after the data workshop (DW), but most address analyses developed following the DW's guidance. For this section, comments are generally limited to topics that deviated from DW intent for some reason. For the ultra-historical data, there were no formal recommendations from the DW on how to construct it. (There was some discussion of trying for longer histories in the context of the DW biological parameters discussions to potentially provide an improved basis for estimating (from data) a stock-recruitment relationship, but it was not a topic the DW statistics groups highlighted in the DW report.)

1). Historic Time Series of landings: Details of the reconstruction of an 'ultra-historical' commercial catch series are available in AW-22. Ultra-historical shrimp effort reconstruction is described in AW-23. Figure 1, reproduced from AW-22, highlights the major features of the reconstruction. Based upon comments received and further investigation, there were changes from the 'first cut' at the extended time series available at the first AW session (from Schirripa and Legault 1999) to the time-series used in assessment modeling reported herein.

2). Catch at age modeling: The DW recommended that growth curves be fitted as needed for the AW to allow for region or stratum variations, and that two separate data sets on reproductive parameters be combined for a new analysis. New analyses following these guidelines were presented at the first AW session (as AW-1 and AW-5), and resulted in a picture with more potential production at younger ages than seen in previous assessments. The matrix of catches at age developed using Goodyear's (1997) procedure was compared with the weighted observed age composition (otolith samples available for the 1990s and particularly since the late 1990s); it was noted that the differences in proportions at age appeared larger for the commercial handline than for longline or recreational. It was noted that both the Goodyear probabilistic catches at age and observed catch at age (based on raw frequencies see AW 19) were used for the ASAP analyses while the VPA analyses only used the probabilistic catch at age and CATCHM analyses used on the observed age composition.

3) An alternative index of abundance from the SEAMAP trawl data was developed (AW-25). An index was needed in this form for the Goodyear catch at age procedure. The index was also more similar in nature to indexes used in past assessments than the AW-15 indexes, and so was useful for evaluating continuity using ASAP with updated data.

4) An estimate of M at age 1 was derived as a distribution in AW-15, based on SEAMAP trawl data. The central tendency of this distribution was a bit higher (~0.6 per year) than most participants at the DW had been considering (although the DW had not reached consensus on a value or set of values to recommend).

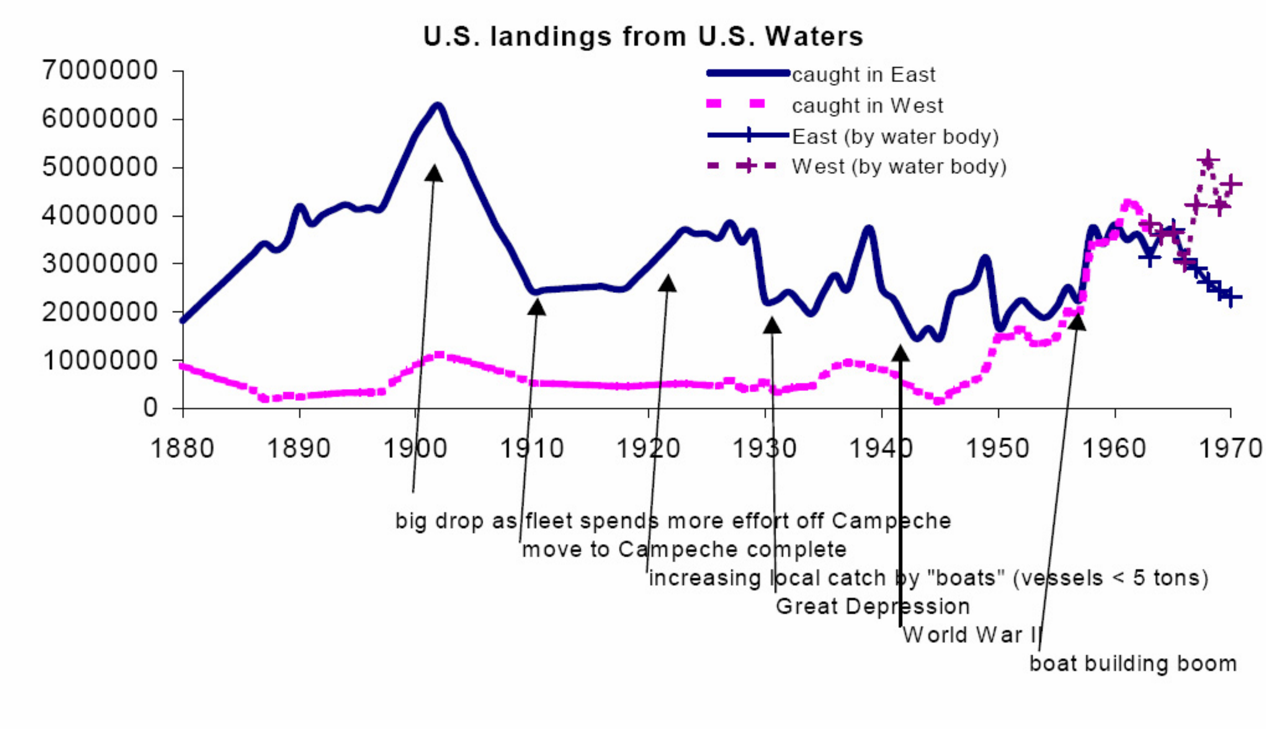

Figure 1. Reconstructed 'commercial' landings (pounds) of red snapper caught in the U.S. Gulf of Mexico (east or west of the Mississippi River) for the years 1872-1962 (lines without symbols) compared to similar statistics for 1963 through 1970 when water body information was recorded (lines with + symbols). Arrows connect trends with important historical events.

Stock Assessment Models and Status of Stock Results

The AW meeting was actually split into two sessions. The first session heard summary presentations of papers following up recommendations from the DW, and took a preliminary look at model results, mainly to understand the properties and sensitivities for the analyses to come later. The second session heard model results from interim analyses, and selected a set of final instructions to those running recommended approaches. For more details of the session discussions, see the "Proceedings" document that follows.

Several modeling approaches were considered, for which there are supporting documents in the Appendixes. In summary, the ASAP model used in the most recent assessments exhibited instability when used to address the "ultra-historical" time series and to a lesser extent with the shorter time series (1962-2003 and 1984-2003). Modifications to the ASAP code have reduced, but not eliminated that instability. The newly developed model, CATCHEM, was selected as the primary model by the AW. CATCHEM is in many ways a generalization of the ASAP approach, with more flexibility, better mathematical rigor due to internalizing the catch at age fitting, and the ability to model geographic substructure. Technical details for the CATCHEM model are described in AW- 6 and AW-27. Discussion during the first AW session about the dangers of confounding between changes in abundance and fluctuations in dome-shaped selectivity patterns resulted in a recommendation that any forward age-structured model results be compared with results from VPA models. The VPA models are described in AW-28 and AW-29. A stock reduction analysis (SRA, also referred to as the Gaming Model, see AW-26 and AW-11, with revisions) was considered, although the model's author (McAllister) recommended it be used primarily to gain insight, and not for management advice calculations. Nevertheless, the contrast between the SRA results and the preliminary results with other models using shorter time series provided impetus for the development of the 'ultra-historical' data series.

Ideally, comparisons among models would be made with identical inputs, but this was not completely possible due to the different modeling structures, and particularly with ASAP, the presence of legacy, 'hard-wired' components that made manipulation difficult. It was also impossible to compare models over every sensitivity case, *i.e.* a 'balanced' set of comparisons. Comparisons chosen reflected those deemed most important by the AW group for examining sensitivities, and for those done subsequent to the second AW meeting, by Miami assessment staff. During the second AW session, the group was satisfied by comparisons between VPA results and CATCHEM results, which indicated that serious confounding between abundance and selectivity changes were unlikely. CATCHEM and SRA results also matched within the limits expected, given the complex vs simple mechanistic structures modeled. Concern about the stability of ASAP, its inability to find a solution in the 'ultra-historical' cases examined, and the difficulties presented by the hard-wired components were important factors which led the AW group to select CATCHEM as the model of choice. However, CATCHEM has a disadvantage: run-times are long, sometimes exceeding 24 hours on even the newest computers. It was not practical to do all sensitivity comparisons suggested within CATCHEM in the available time. Therefore, some of the sensitivity cases were considered only within ASAP (some abundance index exclusions, juvenile M bootstrapping, some steepness values) or VPA (initial age 0 or 1).

CATCHEM model

The CATCHEM model was developed as an alternative to the two-step approach used in prior assessments where the number of fish discarded owing to minimum size limits are determined by use of the ‘probabilistic’ method of Goodyear (1997) and then used along with indices of abundance in an age-structured model (ASAP or VPA). Ideally, these two steps should not be independent because the indices of abundance contain information on relative cohort strength that is pertinent to the number discarded. Moreover, by accounting for the length structure of the population internally, the CATCHEM approach is able to track the abundance of the fraction of the population that can be landed (is above the size limit), which allows for the use of indices of landings per unit effort such as the time series based on handline logbooks. Another advantage of the CATCHEM approach is that it that can accommodate two (or more) stocks fished by multiple fleets in two (or more) areas. Finally, there are a number of features built into the existing code that were not used in the present assessment (such as fitting to length composition data and accommodating movements between areas) owing to other pressing issues for the current assessment. For further details on the model and statistical algorithm see AW-6 or AW-27. The AD Model Builder code for CATCHEM is listed in Appendix 9.

A number of different runs were made applying the CATCHEM algorithm to catch and effort data extending from 1872 to 2003 (summarized below and in AW-27). In addition, runs were made with shorter data streams, one using only data collected since 1962 and the other using data collected only since 1984, to examine the sensitivity of the outcomes to these variations in time series and assumptions. These are summarized below and presented in more detail in RW 1.

Methods

The CATCHEM algorithm was applied to information on red snapper populations in U.S. waters during the years from 1872 to 2003. Five fisheries were designated for each of two regions (east and west): handline, longline, recreational, closed season discards and shrimp bycatch. Three four-month seasons were modeled, starting in January. Spawning was assumed to occur during the second season. Spawning was also assumed to be independent of natal origins, *i.e.*, there is no site fidelity. Thirty age classes were modeled starting with age 1, with the number of age 1 fish being computed as a Beverton and Holt function of the spawn produced during the preceding year. This approach essentially assumes that the bycatch rate is negligible compared to mortality rate owing to natural density-dependent processes during the first year of life.

Data employed.

The commercial landings from 1963 to 2003 are discussed in AW 17, and the landings prior to 1963 are discussed in AW-22 (Appendix 1.Table 1). The annual recreational harvest since 1981 is based on the NMFS Marine Recreational Fishery Statistical Survey (MRFSS), Texas Parks and Wildlife Survey and NMFS headboat survey as described in AW 3 (Appendix 1.Table 2). The recreational harvest statistics used for earlier years (1946-1980) were reconstructions based on U.S. census data using methods described in AW 16 (Appendix 1.Table 2). It is assumed that prior to 1946 the recreational take was negligible in comparison to the commercial take owing to the relative inaccessibility of the fishing grounds (powered vessels were few and expensive, making offshore trips mostly a pastime for the wealthy). The bycatch of juveniles from the offshore shrimp fishery is based on the series produced in DW-54 and discussed by AW 23, which extends back to 1972 (Appendix 1.Table 4). A time series of offshore shrimping effort, which extends for the entire history of the fishery, was also used to tune the model (see AW-23) (Appendix 1.Table 4). The catch during the closed season was derived as described in AW 18 (Appendix 1.Table 3).

The discards from the recreational and commercial fleets during the open season were assumed to occur predominantly due to the regulations on minimum size. They were computed on a seasonal rather than annual basis to better accommodate the rapid growth exhibited by younger red snapper. The population growth curve and coefficient of variation of length about age were fixed to the values estimated in AW 1.

The CV’s used to weight the landings data for model fitting were fixed at 0.1 (an arbitrary low value) for the commercial fleets inasmuch as they represent a near census. The exceptions are for years when no census was taken, in which case the effective CV’s were computed from the census estimates immediately before and after the year in question (absolute difference divided by the mean); the reasoning being that the true value likely lies somewhere between those values. The CV's for the recreational catches after 1981 came from the variance estimates produced by the MRFSS (Diaz, pers. comm.); the CV's for the catch inputs prior to 1982 were assigned arbitrary high CVs (1.0) inasmuch as they were not actually observed., but extrapolated based on US human census estimates of Gulf states coastal county populations. The CV's for the shrimp bycatch are based on the CV's of the overall index (ages 0-2), but modified by the proportion that are not age zero (see AW 23). An additional process variance term was not included for the catch, it being assumed under the assumption that process variations in catch are adequately modeled by inter-annual deviations in recruitment and fishing mortality rates.

Ten indices of abundance were used, 5 for each region (east or west) (Appendix 1.Table 5). These include the handline CPUE series based on log books (DW-47), the MRFSS recreational indices (DW-41), SEAMAP larval indices (DW-14), SEAMAP trawl survey (DW 2) and video surveys (DW-15). The handline logbook indices were modeled in this case as landings per unit effort rather than catch per unit effort, thereby taking into account the potential discards owing to the minimum size limit and removing the major objection to their use by the August, 2004 SEDAR panel. The SEAMAP larval indices were assumed to index the effective number of spawners (abundance in number weighted by the relative fecundity at age) and the video surveys were assumed to index the overall stock. The CV's for the indices of abundance are based on the year-specific estimates that come from the GLM-based procedures used to standardize them (see the references cited above). These are regarded as representing observation variance. To this the model adds an internally-estimated process variance term, which is intended to represent random discrepancies between the trends in the indices and the trends in the actual population they purport to track.

The age composition (and effective sample sizes) used for the commercial and recreational fisheries is described in AW 19 and is presented in (Appendix 1, Tables 9 and 10). Inasmuch as the model makes seasonal calculations with spawning occurring during the second season (midyear), the data for each year were aggregated by the actual integer age in years (i.e., it is not necessary to shift the ages by 0.5 to track cohorts as VPA and ASAP must do). The age composition for the shrimp bycatch was based on model output from AW 20 (Appendix 1, Table 11). The age composition used for the closed season is described in AW 18 (Appendix 1, Table 7).

Parameter specifications

The vulnerability and catchability coefficients for each specific fleet were assumed to be relatively unchanged through time, but allowed to vary with age and among fleets. The relative effort of each fleet was allowed to vary by year essentially as a free parameter (thus the effective selectivity across the mix of fleets (*i.e.* the fishery as a whole) varied noticeably through the years). The vulnerability coefficients for the fishery independent surveys were fixed to 0 for age 1 and 1.0 for ages 2 and older (in the case of the larval indices which are taken as indicators of spawner abundance, the numbers at age are weighted by the fecundity at age vector). The release mortality rates for fish below the minimum size were the multi-year regional values shown in Table 6.5 of the Data Workshop Report.

Natural mortality was fixed to 0.6 yr^{-1} for age 1 and 0.1 yr^{-1} thereafter based on prior decisions of the AW participants. The fecundity at age (including maturity) was set to the vector derived from the age-conditioned model described by AW 5, normalized to a maximum value of 1 (at age 30). Thus, the spawning stock estimates, S, are *not* the actual number of eggs produced by the population, but should be interpreted as the effective number of fully-productive spawners, *i.e.* the number of eggs produced by the spawning population relative to the number that would have been produced if all of the spawners were 30 years old.

Likelihoods and priors.

The catch, effort, and relative abundance indices were assumed to be approximately lognormal distributed. Age composition was assumed to be multinomial distributed. For stock-recruitment, a lognormal prior (see DW 49) was imposed on the model parameter α (see AW 6 or AW 27) with a median value of 13.3 and log-scale variance of 1.28 (equivalent to a mean steepness of about .86). The remaining parameters were treated as free parameters constrained to lie with bounds that encompassed the range of plausible values (essentially the same as specifying uninformative priors over the feasible range).

Benchmark calculations.

As discussed earlier the potential and standard for recovery depends on the way the benchmark is defined. Several MSY and SPR-based benchmarks were examined here. In all cases the fleet-specific vulnerability patterns used in the projections were set equal to the estimated values (which in this case are constant through time) and the minimum size limits for each fleet were assumed to remain unchanged. Furthermore the relative allocation of effort between east and west is assumed to remain at current levels (2001-2003 average). Equilibrium recruitment is assumed to follow the pattern dictated by the estimated Beverton and Holt spawner-recruit relationship.

Three types of MSY-related reference points were considered. The first assumes that the effort of the directed fleets can be scaled down to maximize long-term landings, but that the shrimp bycatch and closed season discards will continue at current levels (i.e., are not controlled). Hereafter the yield associated with this long-term strategy shall be referred to as MSY{current-shrimp}. The second type defines MSY as the maximum long-term landings that could be achieved in the absence of offshore shrimp trawling, hereafter referred to as MSY{no-shrimp}. The third alternative defines MSY in terms of the entire fishery, assuming the effort of all fleets, both directed and undirected, can be scaled down simultaneously by the same proportion. In previous assessments this has been referred to as the "linked-selectivity" or "policy neutral" approach because all fleets endure the same proportional reduction in effort (technically this is policy-neutral only with respect to red snapper, other important concerns notwithstanding, but lacking a decision on allocations to be divided amongst the shrimp and directed fisheries for guidance). Hereafter this definition shall be referred to as MSY{linked}.

One disadvantage of MSY-based reference points, such as have been discussed so far, is that the corresponding biomass targets change with the vulnerability pattern. For example, the estimates for S_{MSY}{current-shrimp} turn out to be less than half of S_{MSY}{no-shrimp}. Clearly policies based on the former are more risk-prone relative to red snapper than policies based on the latter. Moreover, in cases where one stock is larger and more productive than another, MSY-based policies can sometimes lead to the extirpation of the less productive stock. A more stable and potentially less risky policy might be based on maintaining a particular spawning potential ratio (SPR). While the fishing mortality rate associated with a given SPR ($F_{\%SPR}$) depends on the current vulnerability pattern, the corresponding long-term spawning potential ($S_{\%SPR}$) does not. For this paper the value of $F_{\%SPR}$ is chosen so that the SPR value of the most affected stock is equal to the desired level; the SPR level achieved by the remaining stock being greater than or equal to the desired level.

Sensitivity analyses.

Seven models were considered. The first, model 1, was set up exactly as described above. This was the model selected as the base case by the stock assessment workshop participants. The six remaining models were the same as the base case except for the following changes:

(2) the natural mortality rate on age 1 was reduced to 0.3 yr^{-1}
(3) the logbook-based handline indices were dropped
(4) the length-based fecundity vector was used in place of the age-based version
(5) the steepness was fixed at 0.81
(6) the model was started in 1962
(7) the model was started in 1984.

Note that the use of shorter time series avoids the need for the ultra-historical commercial landings series and, in the case of the 1984-2003 run, also eliminates the need for the ultra-historical recreational harvest series. The disadvantage, of course, is that there is little contrast in the more recent data, making it difficult to obtain reliable estimates of stock status. Moreover, the use of the shorter time series requires information on (or assumptions about) the relative trends in fishing effort for the thirty years prior to the start of the period because the population cannot reasonably be assumed to be near virgin levels (as it was for the 1872 -2003 runs). Otherwise the specifications are the same as for the long time series model and the benchmarks are computed in the same way (defined above).

Results

Model fits to data.

The base model matched the total catch data quite well with the exception of certain unusually high values that happen to have high CV's associated with them (Figure 2). These include the 1983 peak in the eastern recreational catch series and the high shrimp bycatch during some of the early years. The model fit most of the indices of abundance reasonably well (Figure 3), but could not reconcile the increasing trend in the western larval index (representing spawners) with the flat or declining trends indicated by the other western indices. The model fits to the SEAMAP trawl series show a strong residual pattern where the predictions for the early years are considerably lower than the trawl values, but the predictions for the later years are considerably higher. The mismatch for the early years can be attributed the very high CV's associated with those data. The mismatch in more recent years reflects the influence of the bycatch data, which, in the context of relatively constant effort, suggests recruitment generally has increased in recent years. The shrimp effort series were fit very well (Figure 4) owing to the relatively low observation CV's assigned to those data (10%). The fits to the age composition data, aggregated over all years, appear to be quite good (Figure 5). It should be kept in mind, however, that the fits to individual years are noisier, particularly where the sample size was small.

The fits obtained with the six sensitivity models are not shown as they were essentially indistinguishable from the fits of the base model.

Parameter estimates.

The estimated vulnerability and apical fishing rates (*F)* for the base model are shown in Figure 6 (note that the fishing rate is somewhat greater than the fishing *mortality* rate unless all discarded fish die). In general, the vulnerability of red snapper to the recreational and commercial hand line fleets follows a dome-shaped pattern with a peak at age 1 or 2 for the former and at age 5 for the latter. (It should be reiterated that the vulnerability coefficients reflect the probability of being caught and includes undersized fish; the probability of being caught and landed is the vulnerability coefficient multiplied by the probability that a fish is greater than the size limit.) The vulnerability of red snapper to the commercial long line fleet follows a logistic pattern with older animals (10+) being the most vulnerable. The vulnerability patterns for the closed season "fleets" were between the hand line and longline. As expected, age1 fish were much more vulnerable to shrimp trawls than age 2 or older.

The estimated trends in apical fishing rates indicate persistent increase for all fleets. Although the recreational fishing rate in the east appears to have declined markedly in recent years, it remains at rather high levels. The highest rates were exhibited by the western shrimp fishery followed by the eastern recreational and western commercial handline fisheries. Note, however, that the high shrimp bycatch rates applies to a single age group with 100% mortality, whereas the lower apical *F'*s estimated for the handline and recreational fleets apply to multiple age classes where some of the undersized animals that are discarded survive. The trends in apical *F* and vulnerability for the four sensitivity runs were quite similar to the base model.

These data do not suggest a strong relationship between the number of recruits and the effective number of spawners (*S*) in the previous years (see Figure 7). In six of the seven runs the estimates of the maximum potential spawn per recruit (α) were near the limit of 151 imposed by the model, which translates to a steepness of 0.974 and in the seventh (1962-2003) the estimate was quite similar (0.96).

Estimated population trends.

The estimates of historical trends in the effective number of spawners and age 1 recruits are shown for the long time series in Figure 7. Under pristine conditions, the western population of red snapper in U.S. waters is estimated to have been about three times as large and three times as productive as the eastern population. The eastern population, which was fished hard early in the 1900's, shows the first signs of decline. The western population is not estimated to have declined substantially until the 1950's. By the 1980's both populations had been seriously depleted and were below the level required to maintain MSY. The extent of the depletion, of course, depends on the way in which MSY is defined (see results in the projection section). Table1 provides various stock status and fishing condition indicators.

The absolute estimates of the number of spawner and number of recruits from the shorter time series are quite similar to the estimates from the long time series (Figure 8). What differs is the perception of potential production and stock status. While all of the models estimate that steepness values of 0.96 or higher, the models based on the shorter time series give estimates of the virgin level of recruitment and MSY that are several times larger than the corresponding values estimated by the models based on the longer time series (see Table 1). On the other hand, the shorter time series also gave rise to higher estimates for S_{MSY}. In summary, the short time series suggest that the stock is much more productive, but also more heavily overfished.

Results More Directly Related to Management Advice

Existing Definitions and Standards

Status determination criteria include a Minimum Stock Size Threshold (MSST), *i.e.*, the overfished criterion, and a Maximum Fishing Mortality Threshold (MFMT), *i.e,* the overfishing criterion. Together with MSY and optimum yield (OY), these 2 parameters are intended to provide fishery managers with the tools to measure fishery status and performance.

Amendment 22 (May 2004) of the Gulf Council's Reef Fish Fishery Management Plan provides the preferred definitions of the overfishing criterion (MFMT) and overfished criterion (MSST) for the Gulf of Mexico red snapper resource. Within that amendment, red snapper MSST is defined as: (1-M) *B_{MSY}, where M is the adult natural mortality rate (0.1), and red snapper MFMT is equal to F_{MSY}. As such, the red snapper resource would be considered undergoing overfishing if F_{CURR} is greater than MFMT and the red snapper resource would be considered overfished if B_{CURR} is less than MSST.

For overfished stocks, a recovery plan must be developed to end overfishing and restore the stock to the biomass level (B_{MSY}) capable of producing maximum sustainable yield (MSY) on a continuing basis. Rebuilding is to occur in as short a time period as possible, but should not exceed 10 years unless conditions dictate otherwise.

Stock Status

Overfishing Definitions and Recommendations.

Under the Council's preferred definition for MFMT (overfishing criterion), the red snapper resource in the US Gulf of Mexico is considered to be undergoing overfishing as our best characterization of the resource from the base model results indicate F_{2003}>F_{MSY} regardless of the form of benchmark calculation (Table 1). The *degree* of overfishing is sensitive to the form of benchmark calculation employed and also is sensitive to steepness and the length of the time-series of data used in the CATCHEM formulation (Figure 9). Other model applications which are not judged as adequate for this stock evaluation provide a broader set of status outcomes (see Appendices). Due to concern over our ability to estimate MSY related benchmarks for red snapper because the underlying stock-recruit relationship is not well determined, a proxy such as $F_{30\%SPR}$, which is consistent with the Council's generic F_{MSY} proxy used for other Reef Fish, may well be more robust for management purposes. In this case, the base model outcomes would still imply overfishing is occurring, although the degree of overfishing would generally be greater..

Overfished Definitions and Recommendations.

Under the Council's preferred definition for MSST (overfished criterion), the red snapper resource in the US Gulf of Mexico is considered to be overfished as the base model results indicate $S_{2003}<.9S_{MSY}$, regardless of the form of benchmark calculation (Table 1). The *degree* of depletion is sensitive to the form of MSY benchmark calculation and to the steepness and time-series of data assumed in the CATCHEM formulation (Figure 9). Other model applications which are not judged as adequate for this stock evaluation provide a broader set of status outcomes (see Appendices). As with the Overfishing Definition, there is concern over our ability to estimate MSY related benchmarks for red snapper because the underlying stock-recruit relationship is not well determined. As such, an MSST definition using a B_{MSY} proxy such as $B_{30\%SPR}$ ($S_{30\%SPR}$ in the CATCHEM jargon) may well be more robust for management purposes.

Control Rule and Recommendations

The rebuilding strategy now adopted by the Council calls for maintaining TAC at 9.12 mp, ending overfishing between 2009 and 2010, and rebuilding red snapper by 2032, with review and adjustment of this policy, as necessary, through periodic assessments while continuously monitoring annual landings to ensure quota is not exceeded. The current assessment indicates that the goals of this policy may not be met and adjustment could be necessary. Stock projections over a wide range of benchmark and future human-induced mortality scenarios are provided in the subsequent section.

Projection methods and assumptions.

The future course of the red snapper population and fishery was modeled through 2032 using the population dynamics equations described in AW-27. Only deterministic projections were made; the stock assessment workshop participants felt that stochastic projections would not be particularly helpful in view of the other uncertainties related to choice of models and reference points.

Future recruitment is assumed to follow the pattern dictated by the estimated Beverton and Holt spawner-recruit relationship. The fleet-specific vulnerability patterns used in the projections were set equal to the estimated values and the minimum size limits for each fleet were assumed to remain unchanged. Until 2007, the effort exerted by the directed fleets (commercial and recreational) was set so as to achieve landings equal to the current TAC of 9.12 million pounds (mp). Subsequently, effort was either fixed to various levels (including zero, "current", and several different benchmarks relating to MSY and spawning potential ratio) or determined numerically by matching an imposed catch quota (TAC) on the directed component of the fishery. In case of the latter, it was not always possible to achieve the higher TACs for all of the projection years. In such cases the model selects a catch schedule as close to the TAC as possible without completely extirpating the stock before 2032. In deriving this schedule, the model assumed that the fishery is more likely to attempt to meet the quota during the earliest years of the projections than in subsequent years.

The effort exerted by offshore shrimp trawlers was set equal to "current levels" (2001-2003 average). In some projections the shrimp effort (not bycatch) was reduced by various percentages beginning in 2007. Closed season effort was assumed to remain at the 2001-2003 average regardless of the way the directed fishery was managed. In point of fact the duration of the closed season will likely increase with decreases in TAC, so the number of red snapper discarded may also increase. However, the extent of the increase is unclear owing to the vagaries of human behavior. Inasmuch as the matter was not discussed by the assessment panel participants, it was assumed that closed season effort would be relatively unaffected by the magnitude of the TAC.

Projection results

Projected trends in the effective number of spawners and total landings from the base model are shown under various scenarios in Figure 10. The spawning stock reference points in this figure is S_{MSY}{current-shrimp}, which assumes only the effort of the directed fleets can be scaled down to maximize long-term landings while the shrimp bycatch and closed season discards continue at current levels. The corresponding values of MSY{current-shrimp} are estimated to be about 3million lbs for the east and 3.4 million lbs for the west (the value for the west is similar to the value for the east owing to the much larger western shrimp bycatch). The effective number of spawners in the eastern and western populations are estimated to have been reduced in 2003 to 39% and 50%, respectively, of S_{MSY}{current-shrimp}. The effective spawner levels associated with the S_{MSY}{current-shrimp} benchmark equates to 12.9% and 5.2% of unfished levels in the east and west, respectively. The effective spawner estimates for 2003 equate to ~5% in the east and ~2.5% in the west relative to unfished conditions (Table 1). The current fishing mortality rate exerted by the directed fleet is estimated to be about 2.3 times greater than F_{MSY}{current-shrimp}benchmark. Not surprisingly, the projections indicate that the current TAC of 9.12 million lbs (Figure 10a) is not sustainable. Current levels of effort (Figure 10b) may be sustainable, but the model predicts the population will be driven to even more dangerously low levels. The 9.12 million lb TAC may be sustainable with a severe reduction in shrimp bycatch (Figure 10c), but the spawning stock would remain well below S_{MSY}{current-shrimp}. On the other hand, the spawning stock is projected to recover to the S_{MSY}{current-shrimp} standard in less than ten years in the absence of any directed harvest (Figure 10d, assuming closed season discarding does not increase). Generally speaking, similar estimates of the current and projected status of the stock were obtained with the sensitivity models (see Table 1 and Figure 11).

As mentioned previously, the recovery targets depend on the way MSY is defined. In the results just considered (Figures 10 and 11), MSY was defined as the maximum long-term landings that could be achieved with current levels of offshore shrimp trawling and closed season bycatch, *i.e.*, MSY{current-shrimp}. An alternative is to define MSY as the maximum long-term landings that could be achieved in the absence of offshore shrimp trawling, *i.e.*, MSY{no-shrimp}. In that case the estimates for MSY{no-shrimp} are greater (3.7 million lbs for the east and 9.2 million lbs for the west), but the corresponding value of S_{MSY}{no-shrimp} is also greater (Figure 12a and Table 1). The effective spawner levels associated with the S_{MSY}{no-shrimp} benchmark equates to 13.6% and 11.3% of unfished levels in the east and west, respectively. As a result of using this benchmark definition, the stock condition is estimated as even more overfished; the estimates of the effective number of spawners in 2003 for the east and west are only 37% and 21% of S_{MSY}{no-shrimp}, respectively (Table 1). Current levels of directed fleet fishing mortality are estimated to be 2.1 times greater than F_{MSY}{no-shrimp}.

The third alternative, MSY{linked}, which scales the effort of all fleets (directed and bycatch) by the same proportion, paints an even less optimistic picture of stock status because it assumes closed season discards can also be scaled back. The estimates of MSY{linked} for the east and west are 3.7 and 8.4 million lbs, respectively. Spawning levels in 2003 for the east and west are estimated to be 16% and 10% of S_{MSY}{linked}. The effective spawner levels associated with the S_{MSY}{linked} benchmark equates to 30.3% and 24.3% of unfished levels in the east and west, respectively. Current levels of fishing mortality across all fleets (shrimp and directed) are estimated to be about 3.6 times greater than F_{MSY}{linked}.

Projections of the base model suggest that, whichever definition of MSY is adopted, the spawning stock will recover by 2032 (Figure 12a) provided the various fleets fish at the corresponding F_{MSY} level (Figure 12a). It must be emphasized, however, that this rate of recovery is made possible by the series of strong year classes (greater than expected from the spawner recruit relationship) estimated to have occurred over the last decade. If the recent recruitment levels are not as high as indicated, then recovery will take very much longer unless fishing is further reduced. Moreover, if the future effort levels for some components of the fishery are higher than those associated with F_{MSY}, then the initial recovery, if achieved, to S_{MSY} may not be sustainable. For example, if managers were to select MSY{no-shrimp} or MSY{linked} targets, but the shrimp fishery continued at current levels, then S_{MSY}
will not be achieved (Figure 12b).

Trajectories of yield and relative spawning potential for SPR levels of 5%, 10% and 20% are shown in Figure 13. The trends under the F_{MSY} {current-shrimp} policy closely match the trends under an $F_{5\%SPR}$ {current-shrimp}, while the trends for the F_{MSY} {no-shrimp} policy look more like the trends for the $F_{10\%SPR}$ {current-shrimp} policy. SPR levels greater than 20% cannot be attained under current levels of offshore shrimp effort even with no directed harvest. Generally speaking, policies based on maintaining such low SPR values are regarded as extremely risk prone for most stocks.

As mentioned previously, the SEDAR stock assessment workshop participants selected Model 1 as the most plausible of the formulations presented. They requested additional projections of that model under various total allowable catch (TAC) and constant F scenarios. These are summarized as isopleths of S/S_{MSY} and S/S_0 (which is essentially the same as SPR for the high steepness cases). Figure 14 presents S/S_{MSY} and S/S_0 isopleths generated from short-term projections to the year 2010 under various levels of TAC (Gulf-wide total allowed landings) and percent reductions in effective offshore shrimp effort. Here MSY (and S_{MSY}) are conditioned on the current state of the fishery as described for MSY{current-shrimp}, except with a presumed reduction in offshore shrimp effort. In Figure 14a the presumed reduction in offshore shrimp effort used to compute MSY was fixed at 40% for all projections. Accordingly, the graph should be interpreted as an indication of what might happen if managers based the MSY definition on an assumed 40% reduction in shrimp effort but the actual reduction in shrimp effort was as indicated on the horizontal axis (note that, by this definition, MSY cannot be achieved unless the actual reduction in shrimp effort at least 40%). In Figure 14b, the presumed reduction in offshore shrimp effort used to compute MSY varied with the value indicated on the horizontal axis. Hence, the graph should be interpreted as an indication of what might happen if managers based the MSY definition on the actual reduction in offshore future shrimp effort (implying that managers can either control or accurately forecast future shrimp effort). The S/S_{MSY} isopleths in Figure 14b decrease with reduced shrimp effort rather than increase as in Figure 13a because the denominator S_{MSY} used to generate Figure 14b also increases with reduced shrimp effort (*i.e.* a changing baseline).

Figure 14 suggests that the current TAC of 9.12 million pounds cannot be sustained and will lead to continued depletion of the stock. Reductions in the offshore shrimp fleet have little impact on the projections for the east, but substantially impact the recovery in the west. However, even with zero shrimp effort, the TAC would need to be decreased to under 3 million lbs in order to bring about a full recovery within the next five years. Perhaps more importantly, the projected values of S/S_0 are very low and would not be expected to increase above 15 percent within 5 years even with no fishing. The situation is somewhat more optimistic with a longer recovery time (Figures 15a and 15b). The graphs suggest a full recovery is possible by 2032 if the TAC is reduced to about 6 million lbs regardless of what occurs in the shrimp fishery (slightly larger TACs may be permissible if the offshore shrimp fleet effort is reduced). Values of S/S_0 of 20% or better are possible be achieved in 2032 with TACs between 2 and 3 million pounds and shrimp effort reductions of 40% to 50%.

Figures 16 and 17 show isopleths similar to those above, but for various levels of directed fishery mortality rate (expressed as a fraction of current levels). The implications, of course, are similar to the TAC-based isopleths. Current levels of effort in the directed fishery will keep both the eastern and western stocks depressed below 5% of S_0 regardless of what happens in the offshore shrimp fishery. Modest S/S_0 values of even 20% cannot be achieved for the western stock by 2032 unless the directed fishing effort is reduced by 90% and the offshore shrimp effort is reduced by 80% or more (Figure 17).

Discussion

Previous assessments (since the early 1990's) of gulf red snapper indicated the stock was overfished and undergoing overfishing by different standards (either SPR or linked selectivity MSY benchmarks). Based on previous assessments, it was determined that even if the directed fishery was closed and all juvenile red snapper bycatch from the shrimp fishery was halted, rebuilding to B_{MSY} levels would exceed 10 years. The longest rebuilding period recommended by the National Standard Guidelines is the time to recover in the absence of fishing mortality plus the mean generation time which was previously estimated as 19.6 years for red snapper. The Gulf of Mexico Fishery Management Council thus set a recovery target date of 2032 or earlier for the stock. This rebuilding timeline and threshold replaced the previously (in 1996) established rebuilding schedule for red snapper, which required adjustment of total allowable catch (TAC) biannually to maintain a rebuilding trajectory that rebuilds the red snapper stock to 20 percent transitional SPR by 2019. The rebuilding strategy now adopted by the Council calls for maintaining TAC at 9.12 mp wwt (whole weight), ending overfishing between 2009 and 2010, and rebuilding red snapper by 2032, with review and adjustment of this policy, as necessary, through periodic assessments while continuously monitoring annual landings to ensure quota is not exceeded.

Depending upon the selectivity standard used for benchmark calculations, it is no longer clear that the red snapper resource would require more than 10 years to rebuild. This result was also evident in an independent assessment conducted by Rothschild *et.al.* (1997), which ignored shrimp bycatch. Rebuilding to the lowest biomass standards (those associated with the assumption that current shrimp mortality levels shall not be further reduced), could be achieved in the near future if the directed fishery were sufficiently restrained. However, this implies that the stock need only rebuild to about 5% of the unfished level in the west and about 13% in the east. As noted above such low percentages of the unfished condition are usually considered risky.

Other model results are available in the Appendices and the working documents. These other model applications, which were not judged by the AW participants as adequate for this stock evaluation, provide a broader set of status outcomes than the base model and its associated sensitivity evaluations described above. These results are used in the discussion that follows. More technical detail is available in the Appendices.

The CATCHEM base model fits almost all data presented to it very well. The primary exception is the West larval SEAMAP index, which indicates a strong increasing trend that runs counter to the direction indicated by the other indices. Also the model consistently underestimated the value of some of the higher bycatches. It was suggested that this could be an indicator of post-recruit density dependence, but the points that were poorly fit have very large variances and it is likely that pattern seen is partly a consequence of having to fit landings data with much smaller CVs Nevertheless, it appears that one does not need to invoke additional mechanisms to fit the existing data. CATCHEM appears to have finessed any post-recruitment density dependence with its age 1 start; the problems fitting the historical series without invoking density dependence encountered with the SRA models were not evident in the CATCHEM results. The cost is that any information (and potential production) associated with age 0 snapper is not available.

Nearly all of the CATCHEM runs estimated steepness values near 0.97, essentially the upper bound of the built-in constraints. However, one of the more interesting results with CATCHEM comes from a sensitivity run setting steepness=0.81, rather than allowing internal fitting. Stock status results are qualitatively similar with both steepness conditions within comparable benchmarks. Apparently, the ultra-historical approach has resulted in estimates of stock productivity that are much less sensitive to steepness than seen in past assessments. On the other hand, the estimates of productivity from the CATCHEM model are very sensitive to the duration of the time series used (1872, 1962, or 1984). The estimates of MSY{current-shrimp}, for example, were on the order of 6 mp (east and west combined) when the 1872-2003 time series was used and over 20 mp when the shorter time series were used. In the case of the latter, such high estimates for MSY are difficult to reconcile with the concomitant estimation of an overfished status because the landings in the historical records prior to 1962 are very much less than 20 mp. Hence, if the estimates from the shorter time series are to be believed, then either the historical landings were under-estimated several fold or else there has been a change in the underlying productivity of the stock. The first hypothesis seems unlikely owing to the limited number of fish houses extant prior to the 1960's. On the other hand, mechanisms that would account for a four or five-fold increase in the productivity of the stock are also difficult to envisage. It should also be noted that the solution surfaces for the models based on the shorter time series do not appear as well behaved as those for the models based on the longer time series owing to the lack of contrast in the data; there appear to be several local minima with nearly the same value of the objective function, but very different implications for stock status. Hence, the absolute estimates of productivity from the short time series are rather uncertain and should be interpreted with caution. Nevertheless, the hypothesis that the productivity of the stock has increased in recent years is not inconsistent with the results from the models applied to the longer time series, which indicate that the recruitment levels over the last 20 years were the highest in the history of the fishery despite the very low number of spawners.

Within the ASAP assessment model framework, steepness was fixed at three values: 0.81, 0.90, and 0.95. Almost without exception, the status plots show that the point for steepness = 0.81 is the least overfished (relatively speaking) with the least amount of overfishing occurring. Status for higher steepness values veer diagonally up and to the left from steepness = 0.81 (i.e., toward more overfished and greater overfishing). This is logical, because a lower steepness indicates that the stock has greater potential to recover as stock size increases; or in other words, the higher the steepness value, the less distance there is between current recruitments and virgin recruitment levels. The extreme case is visible in the VPA runs, where steepness is ~1 (indicating near constant recruitment). The variability in VPA runs within a given plot and for a given age of recruitment (assumed to be 0 or 1) is due primarily to whether R_0 was estimated or fixed to a level that corresponds to 8.5 times the three year average low for the time series (1984-2003). In this case, the fixed R_0 sets the virgin benchmark higher, and therefore relative SSB values are shifted to the left (towards greater overfished status); there is much less vertical shift in the overfishing status. Within each fixed steepness, the whole-Gulf ASAP results suggest much less R_0 variation with starting year than CATCHEM for 1962 and 1984 starts, but ASAP could not reach a solution for the 1872 start. The age 0 (ASAP) vs age 1 (CATCHEM) starts may be some of the source of this differencing, but it seems likely that most of this variation represents different placement of some fundamental uncertainties or incompleteness by the two models.

The ASAP models suggest that the perception of stock status is rather sensitive to the level of natural mortality on juvenile (age 0 and 1) red snapper, particularly when steepness is low. The bootstrapping analyses of the ASAP applications to the 1962-2003 Gulf wide time series (RW-5) show that, in general, the status of the stock appears more to be overfished and overfishing appears more likely with increased M. The CATCHEM formulation was much less sensitive to changes in M, starting as it does with age 1 (rather than age 0). Both the CATCHEM and ASAP models provided the best fits to the data with higher levels of early natural mortality, irrespective of steepness values.

VPA was the only assessment model to explore two different ages of recruitment—age 0 or age 1. ASAP looked only at age 0, and CATCHEM looked only at age 1. Stock Reduction Analyses conducted at the AW meeting suggested this to be an important source of variability in status and benchmark estimation, but that work was conditioned upon the ASAP model outcomes, and so it is less clear if the results can be generalized. Modeling the population with recruitment at age 1 is a way of acknowledging that bycatch mortality on age 0, whether additive or compensatory, cannot be estimated apart from natural mortality; thus, all mortality between age 0 and 1 gets combined into the estimates of the stock recruit parameters. For Gulf-wide and East model applications, the status for assuming age 1 recruitment (ignoring age 0 fishery-induced mortality) is shifted to the right of age 0 points, i.e. less overfished. There is also a slight shift downward in the biomass status point, i.e. less overfishing, but this is much less than the shift in overfished status. The pattern in the west model is different, most likely because the western gulf is where the majority of the bycatch occurs. When R_0 is estimated, the status for the model application using age 1 recruitment is to the ***left*** (more overfished) of the age 0 recruitment point. A possible explanation for this is that when the model begins at age 1, it does not have information on the age 0 recruits lost to bycatch and therefore assumes a much less productive stock. The reverse pattern is seen when R_0 is fixed to 8.5 times the 3 year average low recruitment level. In these cases, the status estimated from models with age 1 recruitment is to the right (less overfished) of the age 0 models. This pattern is the opposite of when R_0 was estimated, but it is not a contradiction—in this case, the model already has information that recruitment productivity is high (because it is fixed high).

SRA results were conditional on several ASAP derived inputs, and therefore do not represent a completely independent set of results. However, the model was deemed to provide several important insights.

The SRA model could not fit a plausible trajectory for the 1872-forward period without invoking post-recruitment density dependence. Adding density dependence at either age 1 or age 2 did allow a plausible trajectory, and producing results similar to the ASAP and VPA results presented at the AW. With density dependence, shrimp bycatch reduction had little impact on future trajectories. Recovery by 2032 required a reduction in TAC, and failing to reduce TAC led to a collapse within the next 10 years under this model.

Comparison with past recommendations

Red snapper has been assessed since at least the early 1990s, and the Gulf of Mexico Fishery Management Council's Reef Fish Stock Assessment Panel (RFSAP) recommended appropriate biological catch (ABC) levels multiple times between 1990 and 1999 (Table 2; RFSAP 1990a, 1990b, 1992, 1993, 1995, 1999a and 1999b). Given assumed reductions in shrimp fishery bycatch of 40-50%, the RFSAP recommended ABCs ranging from 0 to 10 million pounds (most were 0 to 6mp) to be able to rebuild the spawning stock to the 20%-30% SPR level within one to three decades. The CATCHEM projections presented above are similar to several of those recommendations in that with 40-50% reductions in shrimp effort and a directed fishery TAC of 2 to 3 million pounds the spawning stock is projected to rebuild to 20% SPR by 2032. It is noteworthy that the shrimp fishery fishing mortality rate has already declined roughly 20% from the 1984-1989 level. Thus this assessment indicates that greater reductions in shrimp effort are needed than projected in the earlier assessments.

Issues of Particular Concern

The new CATCHEM results, which free the management advice to some extent from steepness assumptions, probably rest on the ultra-historical catch series. Supporting documents for the series were sparse, but it seems unlikely that any additional information exists to improve the series. However, the management advice, at least over the short term, appears reasonably consistent among different starting years for the models, and remains generally consistent with advice from past assessments. It therefore seems unlikely that there could be strong misleading guidance resulting from the new analysis. However, it was also clear that the question of the ultimate productivity attainable from this stock was not settled by the ultra-historical approach.

The unexpectedly high value for steepness, high estimates for recruitment since the 1970's, and the sensitivity of R_0 to starting year (but not to steepness) in CATCHEM suggests that there are still important, unmodeled dynamics affecting the long-term variation in snapper abundance. Several possible mechanisms were discussed at the workshop, but at present, all should be consider speculations. The mechanisms mentioned (not exhaustive) included density-dependent mortality in (post-recruit) juveniles; density-dependent mortality in adults; delayed density dependence (adults *vs.* juveniles); changing M over time, not related to snapper density (reduced predator abundances); increasing carrying capacity over time for pre-recruits (oceanographic regime change); increasing carrying capacity over time for adults (oil rigs or other habitat expansions); and stock extending geographically well beyond assumed range (Campeche connection). These are all valid research topics for the next several years, and at this point it seems premature to focus on one to the exclusion of the others. Current data seem unlikely to support serious estimation for any of these effects.

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Table 1. Management benchmarks and stock status indicators for red snapper in the eastern and western Gulf of Mexico from seven CATCHEM runs and under three benchmark selectivity patterns. from seven CATCHEM runs including the base case and six sensitivity tests.

					S/Smsy					F/Fmsy					S/S0					Benchmarks			Current Status	
Area	Model- run	assumption	Benchmark selectivity	Estimated R0 (millions)	1872	1962	1984	1999	2003	1872	1962	1984	1998	2003	1872	1962	1984	1998	2003	MSY (mp)	Smsy	SMSY/S0	Over-fished?	Over-fishing?
east	CATCHEM-1	Base	linked	2.2	3.35	1.03	0.17	0.09	0.16	0.06	1.52	4.99	2.69	3.59	1.00	0.31	0.05	0.03	0.05	3.73	1.80	0.30	yes	yes
east	CATCHEM-1	Base	no-shrimp	2.2	7.64	2.35	0.40	0.21	0.37	0.03	0.80	2.62	1.41	2.08	1.00	0.31	0.05	0.03	0.05	3.69	0.79	0.14	yes	yes
east	CATCHEM-1	Base	curr-shrimp	2.2	8.07	2.49	0.42	0.22	0.39	0.04	0.87	2.85	1.54	2.31	1.00	0.31	0.05	0.03	0.05	3.01	0.75	0.13	yes	yes
west	CATCHEM-1	Base	linked	6.8	4.20	1.97	0.24	0.11	0.10	0.00	0.51	2.89	2.78	3.59	1.00	0.47	0.06	0.03	0.02	8.37	4.53	0.24	yes	yes
west	CATCHEM-1	Base	no-shrimp	6.8	9.35	4.39	0.54	0.25	0.21	0.00	0.25	1.41	1.36	2.08	1.00	0.47	0.06	0.03	0.02	9.22	2.03	0.11	yes	yes
west	CATCHEM-1	Base	curr-shrimp	6.8	21.80	10.24	1.26	0.57	0.49	0.00	0.27	1.52	1.46	2.31	1.00	0.47	0.06	0.03	0.02	3.41	0.87	0.05	yes	yes
east	CATCHEM-2	M 0.3 on age 1	linked	1.6	3.45	1.07	0.19	0.09	0.17	0.06	1.37	4.36	2.78	3.59	1.00	0.31	0.06	0.03	0.05	3.91	1.79	0.29	yes	yes
east	CATCHEM-2	M 0.3 on age 1	no-shrimp	1.6	8.11	2.52	0.46	0.21	0.39	0.03	0.70	2.24	1.42	2.03	1.00	0.31	0.06	0.03	0.05	3.83	0.76	0.13	yes	yes
east	CATCHEM-2	M 0.3 on age 1	curr-shrimp	1.6	8.57	2.67	0.48	0.22	0.41	0.03	0.78	2.48	1.58	2.30	1.00	0.31	0.06	0.03	0.05	3.03	0.72	0.12	yes	yes
west	CATCHEM-2	M 0.3 on age 1	linked	5.7	4.09	1.95	0.23	0.10	0.09	0.00	0.49	2.96	2.86	3.59	1.00	0.48	0.06	0.02	0.02	9.01	5.23	0.25	yes	yes
west	CATCHEM-2	M 0.3 on age 1	no-shrimp	5.7	8.90	4.23	0.49	0.21	0.19	0.00	0.23	1.40	1.35	2.03	1.00	0.48	0.06	0.02	0.02	10.47	2.41	0.12	yes	yes
west	CATCHEM-2	M 0.3 on age 1	curr-shrimp	5.7	22.29	10.59	1.23	0.54	0.48	0.00	0.25	1.52	1.47	2.30	1.00	0.48	0.06	0.02	0.02	3.50	0.96	0.05	yes	yes
east	CATCHEM-3	No Logbook Indices	linked	2.2	3.52	1.03	0.18	0.10	0.17	0.07	1.65	5.17	2.49	3.43	1.00	0.29	0.05	0.03	0.05	0.00	1.68	0.29	yes	yes
east	CATCHEM-3	No Logbook Indices	no-shrimp	2.2	8.18	2.40	0.41	0.23	0.40	0.04	0.87	2.73	1.31	1.99	1.00	0.29	0.05	0.03	0.05	3.58	0.72	0.13	yes	yes
east	CATCHEM-3	No Logbook Indices	curr-shrimp	2.2	8.56	2.51	0.43	0.24	0.42	0.04	0.95	2.98	1.43	2.22	1.00	0.29	0.05	0.03	0.05	2.92	0.69	0.12	yes	yes
west	CATCHEM-3	No Logbook Indices	linked	6.8	4.09	1.95	0.24	0.11	0.10	0.00	0.52	2.95	2.79	3.43	1.00	0.48	0.06	0.03	0.02	0.00	4.68	0.25	yes	yes
west	CATCHEM-3	No Logbook Indices	no-shrimp	6.8	8.51	4.05	0.50	0.23	0.21	0.00	0.26	1.47	1.39	1.99	1.00	0.48	0.06	0.03	0.02	9.59	2.25	0.12	yes	yes
west	CATCHEM-3	No Logbook Indices	curr-shrimp	6.8	19.41	9.25	1.14	0.52	0.48	0.00	0.28	1.59	1.50	2.22	1.00	0.48	0.06	0.03	0.02	3.62	0.99	0.06	yes	yes
east	CATCHEM-4	Fecundity Calculation	linked	2.1	3.41	1.05	0.19	0.11	0.18	0.06	1.52	4.85	2.73	3.59	1.00	0.31	0.05	0.03	0.05	3.74	1.57	0.30	yes	yes
east	CATCHEM-4	Fecundity Calculation	no-shrimp	2.1	7.65	2.36	0.42	0.25	0.40	0.03	0.80	2.57	1.45	2.10	1.00	0.31	0.05	0.03	0.05	3.70	0.70	0.14	yes	yes
east	CATCHEM-4	Fecundity Calculation	curr-shrimp	2.1	8.09	2.50	0.44	0.26	0.42	0.04	0.88	2.81	1.58	2.33	1.00	0.31	0.05	0.03	0.05	3.01	0.66	0.13	yes	yes
west	CATCHEM-4	Fecundity Calculation	linked	6.8	4.28	2.05	0.26	0.12	0.11	0.00	0.51	2.86	2.76	3.59	1.00	0.48	0.06	0.03	0.03	8.39	3.95	0.24	yes	yes
west	CATCHEM-4	Fecundity Calculation	no-shrimp	6.8	9.42	4.51	0.57	0.26	0.24	0.00	0.25	1.41	1.36	2.10	1.00	0.48	0.06	0.03	0.03	9.19	1.80	0.11	yes	yes
west	CATCHEM-4	Fecundity Calculation	curr-shrimp	6.8	21.96	10.51	1.32	0.60	0.55	0.00	0.27	1.51	1.46	2.33	1.00	0.48	0.06	0.03	0.03	3.41	0.77	0.05	yes	yes
east	CATCHEM-5	low steepness	linked	2.8	3.10	0.98	0.20	0.10	0.19	0.07	1.64	4.53	2.16	3.11	1.00	0.31	0.06	0.03	0.06	3.38	2.55	0.36	yes	yes
east	CATCHEM-5	low steepness	no-shrimp	3.1	6.22	2.18	0.41	0.20	0.34	0.03	0.71	2.26	1.18	2.03	1.00	0.35	0.07	0.03	0.05	3.72	1.41	0.21	yes	yes
east	CATCHEM-5	low steepness	curr-shrimp	2.8	5.06	1.59	0.32	0.17	0.31	0.05	1.11	3.06	1.46	2.75	1.00	0.31	0.06	0.03	0.06	2.72	1.57	0.24	yes	yes
west	CATCHEM-5	low steepness	linked	7.8	3.44	1.79	0.30	0.12	0.14	0.00	0.51	3.05	2.97	3.11	1.00	0.52	0.09	0.04	0.04	6.36	6.38	0.33	yes	yes
west	CATCHEM-5	low steepness	no-shrimp	9.0	4.53	2.43	0.41	0.15	0.18	0.00	0.29	1.84	1.71	2.03	1.00	0.54	0.09	0.03	0.04	9.94	5.59	0.27	yes	yes
west	CATCHEM-5	low steepness	curr-shrimp	7.8	12.90	6.72	1.13	0.47	0.52	0.00	0.31	1.84	1.79	2.75	1.00	0.52	0.09	0.04	0.04	2.39	1.70	0.13	yes	yes
east	CATCHEM-6	Start in 1962	linked	5.0	-	0.08	0.06	0.03	0.06	-	6.30	6.10	3.61	4.39	-	0.03	0.02	0.01	0.02	9.33	4.74	0.34	yes	yes
east	CATCHEM-6	Start in 1962	no-shrimp	5.0	-	0.16	0.11	0.07	0.13	-	3.48	3.37	2.00	2.68	-	0.03	0.02	0.01	0.02	9.03	2.33	0.17	yes	yes
east	CATCHEM-6	Start in 1962	curr-shrimp	5.0	-	0.16	0.12	0.07	0.13	-	3.83	3.71	2.20	2.99	-	0.03	0.02	0.01	0.02	7.48	2.23	0.17	yes	yes
west	CATCHEM-6	Start in 1962	linked	25.3	-	0.03	0.04	0.02	0.02	-	4.83	3.94	3.03	4.39	-	0.01	0.01	0.01	0.00	35.59	17.14	0.25	yes	yes
west	CATCHEM-6	Start in 1962	no-shrimp	25.3	-	0.07	0.07	0.05	0.04	-	2.56	2.09	1.61	2.68	-	0.01	0.01	0.01	0.00	38.14	8.29	0.12	yes	yes
west	CATCHEM-6	Start in 1962	curr-shrimp	25.3	-	0.17	0.19	0.13	0.10	-	2.80	2.28	1.76	2.99	-	0.01	0.01	0.01	0.00	12.67	3.21	0.05	yes	yes
east	CATCHEM-7	Start in 1984	linked	5.8	-	-	0.05	0.03	0.06	-	-	4.98	5.27	4.18	-	-	0.02	0.01	0.02	10.68	5.81	0.36	yes	yes
east	CATCHEM-7	Start in 1984	no-shrimp	5.8	-	-	0.11	0.06	0.13	-	-	2.98	3.15	2.77	-	-	0.02	0.01	0.02	8.98	2.81	0.18	yes	yes
east	CATCHEM-7	Start in 1984	curr-shrimp	5.8	-	-	0.11	0.06	0.13	-	-	2.98	3.15	2.77	-	-	0.02	0.01	0.02	8.98	2.81	0.18	yes	yes
west	CATCHEM-7	Start in 1984	linked	31.5	-	-	0.04	0.02	0.02	-	-	3.23	2.97	4.18	-	-	0.01	0.00	0.00	43.80	20.89	0.24	yes	yes
west	CATCHEM-7	Start in 1984	no-shrimp	31.5	-	-	0.19	0.11	0.08	-	-	1.84	1.70	2.77	-	-	0.01	0.00	0.00	16.11	3.90	0.05	yes	yes
west	CATCHEM-7	Start in 1984	curr-shrimp	31.5	-	-	0.19	0.11	0.08	-	-	1.84	1.70	2.77	-	-	0.01	0.00	0.00	16.11	3.90	0.05	yes	yes

Table 2. TAC and ABC recommendations by the Gulf of Mexico Fishery Management Council's Reef Fish Stock Assessment Panel

	TAC or ABC recommendations			range of shrimp bycatch reductions considered		target		strategy	source
	lower	upper	for year	lower	upper	benchmark	year		
1990		0			0%	20% SPR	2000		RFSAP March 1990
1990		0			> 50%	20% SPR	2000		RFSAP June 1990 (revised shrimp bycatch estimates)
1992	4	6.0		40%	50%				RFSAP September 1992
1993	4	6.0			50%				RFSAP 1993
1994		6.0		50%					RFSAP September 1994
1995	6	10.0		50%					RFSAP 1995 October
1998	3	6.0		44%					RFSAP 1998 January and October
1998		0		0%					RFSAP 1998 January
1999	0	5.8		40%		20% SPR	2019	constant catch	RFSAP 1999 September
1999		0		40%		Bmsy	2031	constant catch	
1999	0	9.1		50%		20% SPR	2019	constant catch	
1999	0	2.8		50%		Bmsy	2031	constant catch	
1999	0	2.0	2000	40%		20% SPR	2019	constant F	
1999		0	2000	40%		Bmsy	2031	constant F	
1999	0	3.5	2000	50%		20% SPR	2019	constant F	
1999	0	0.4	2000	50%		Bmsy	2031	constant F	

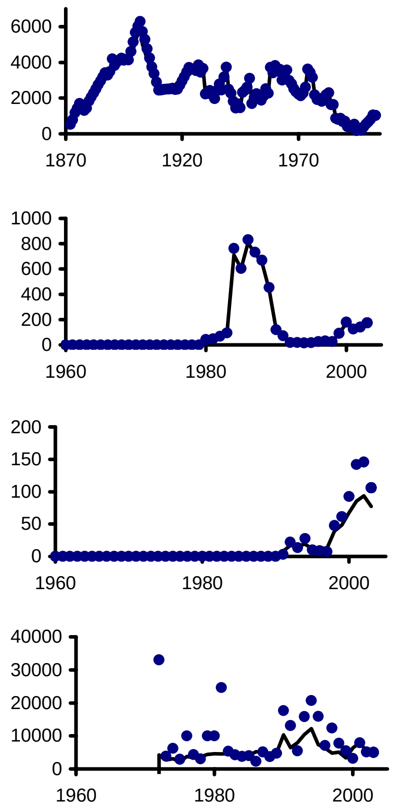

Figure 2. Model fits to the total landings in weight for the handline (HL) and longline (LL) fleets, total number landed for the recreational fleet (REC), and total number killed for the closed season (CS) and shrimp bycatch.

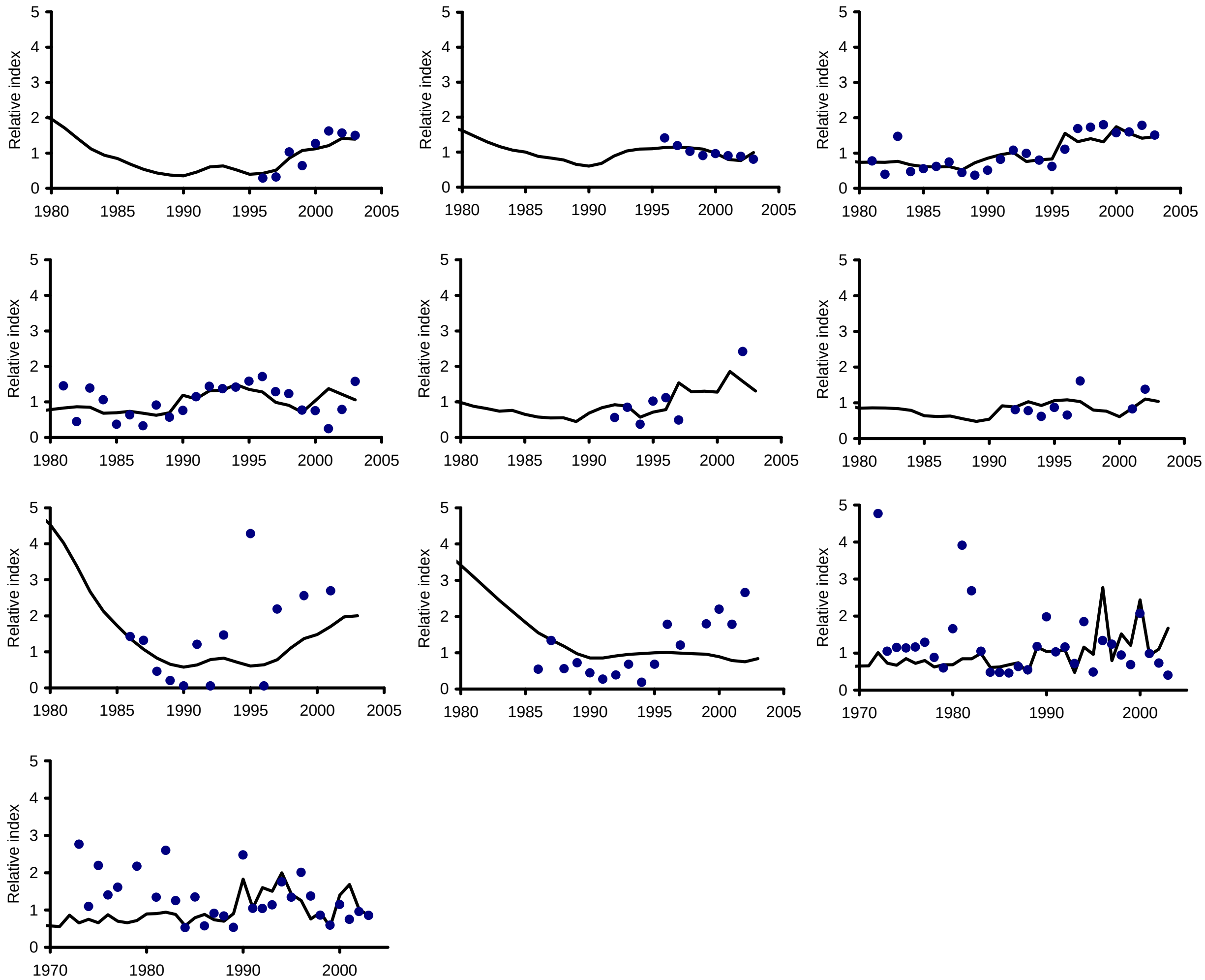

Figure 3. Model fits to indices of abundance (rescaled by the mean of the predicted values).

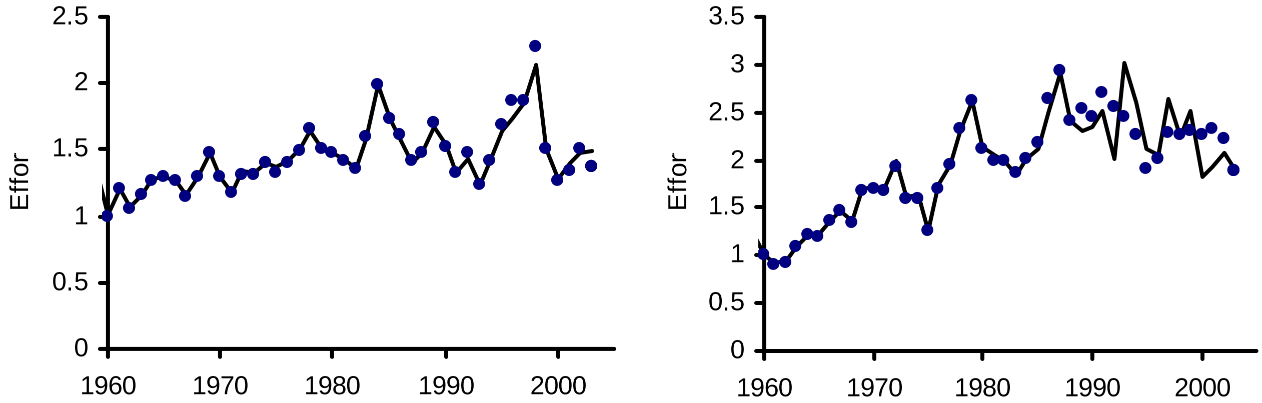

Figure 4. Model fits to the shrimp trawl effort series.

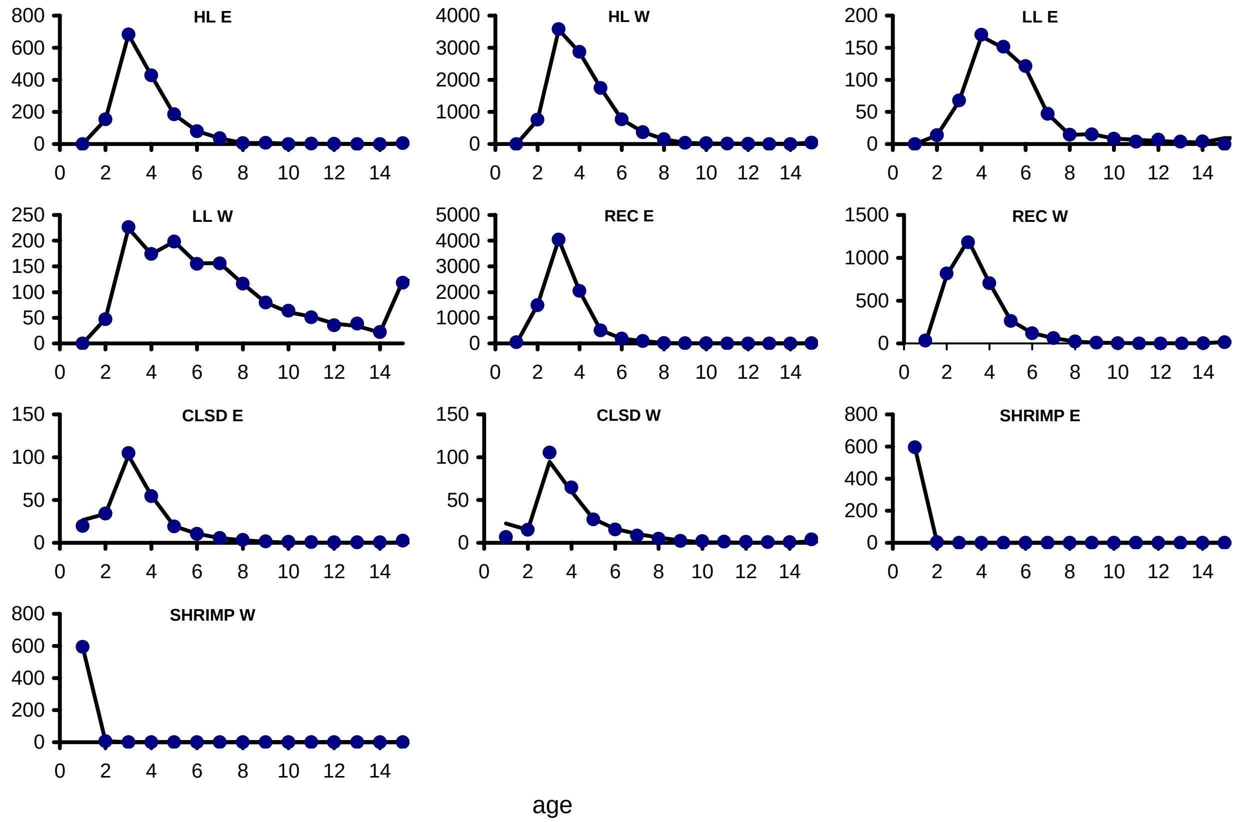

Figure 5. Model fits to the age composition data (aggregated across years).

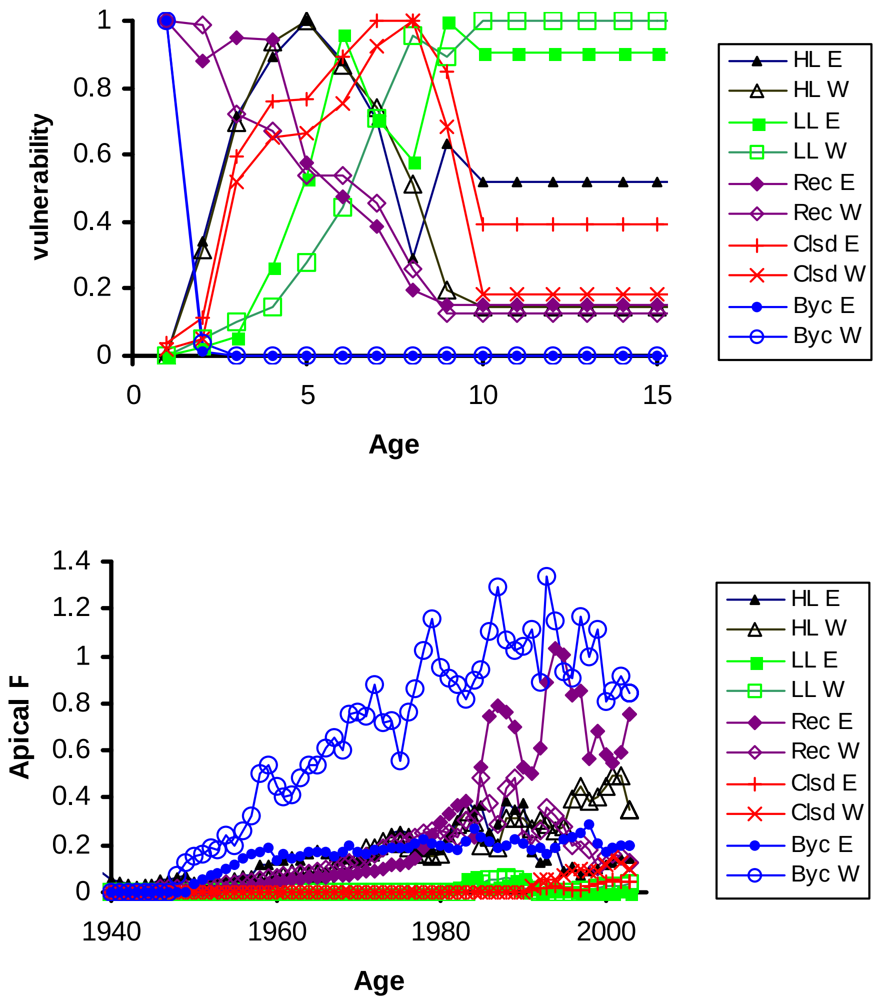

Figure 6. Model estimates of vulnerability and apical fishing rate for each fleet.

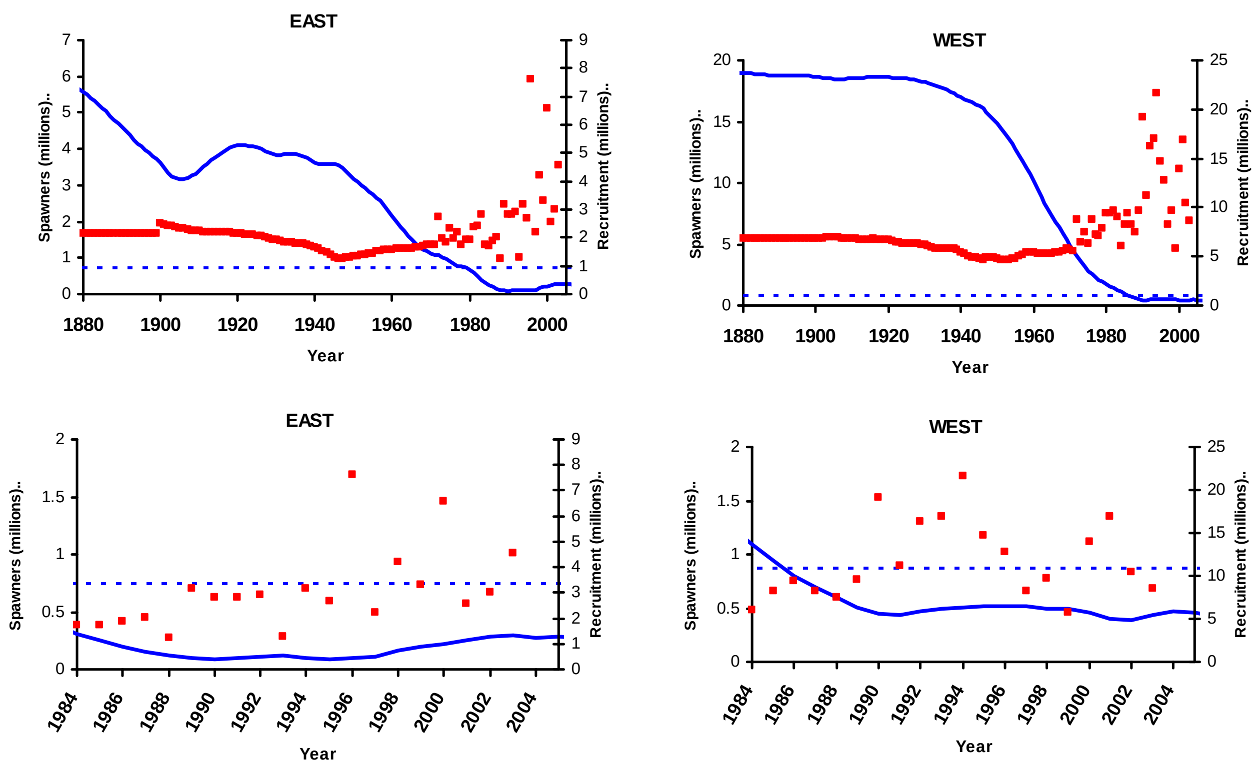

Figure 7. Model 1 estimates of the effective number of spawners (lines) and corresponding number of age 1 recruits (squares). The horizontal line gives the effective number of spawners associated with MSY{current-shrimp}. The upper panels are for 1880-2003 and the lower panels are for 1984-2003.

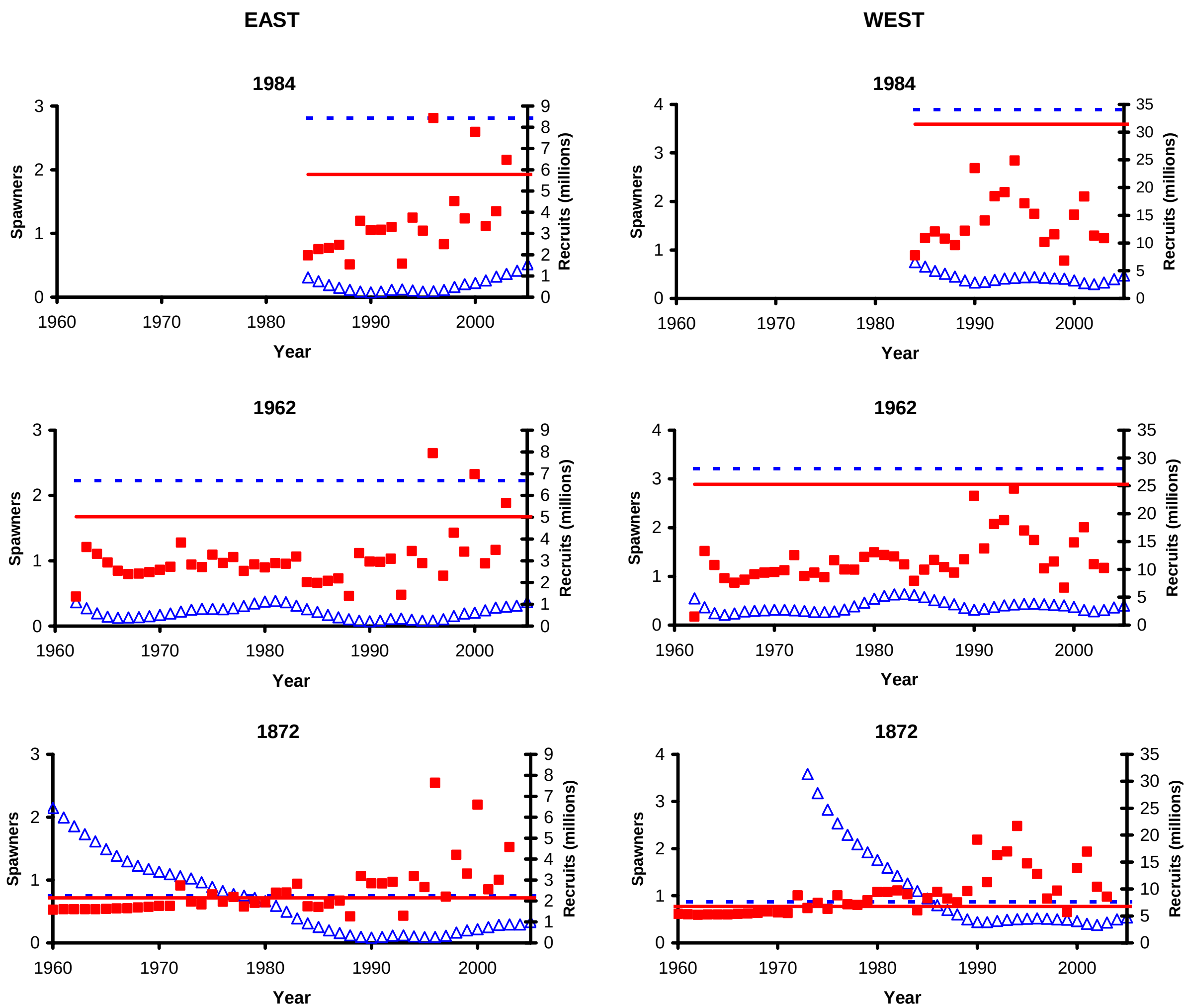

Figure 8. Comparison of model outputs for the three time series: 1872-2003, 1962-2003 and 1984-2003. The square symbols represent the estimates of the number of recruits (*R*) and the triangles represent the estimates of the effective number of spawners (*S*). The estimated effective number of spawners in the west from 1960 through the mid 1970s for the 1872-2003 runs was greater than 4 (see Figure 7) and are not shown.The solid and dashed horizontal lines represent the estimates of virgin recruitment (R_0) and S_{MSY}{current shrimp}, respectively.

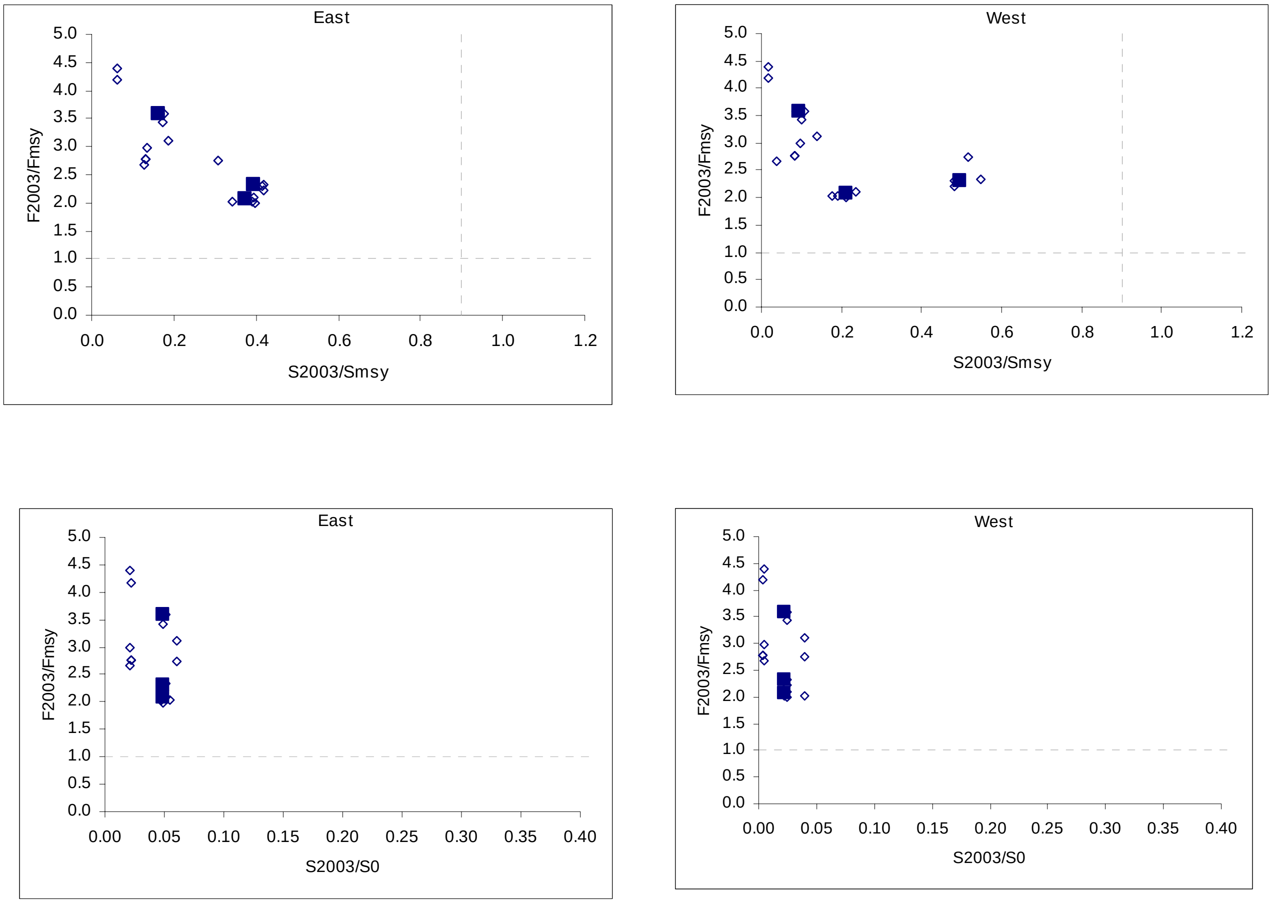

Figure 9. Status determinations for the base CATCHEM model applications (solid squares) and CATCHEM sensitivity analyses (open diamonds) using the 3 different selectivity alternatives for MSY Benchmark calculations. Dashed lines represent the Council's preferred definitions for MFMT (horizontal) and MSST (vertical) Upper plates show results for F_{2003}/F_{MSY} and S_{2003}/S_{MSY}. Lower plates show results for F_{2003}/F_{MSY} and S_{2003}/S_0 .

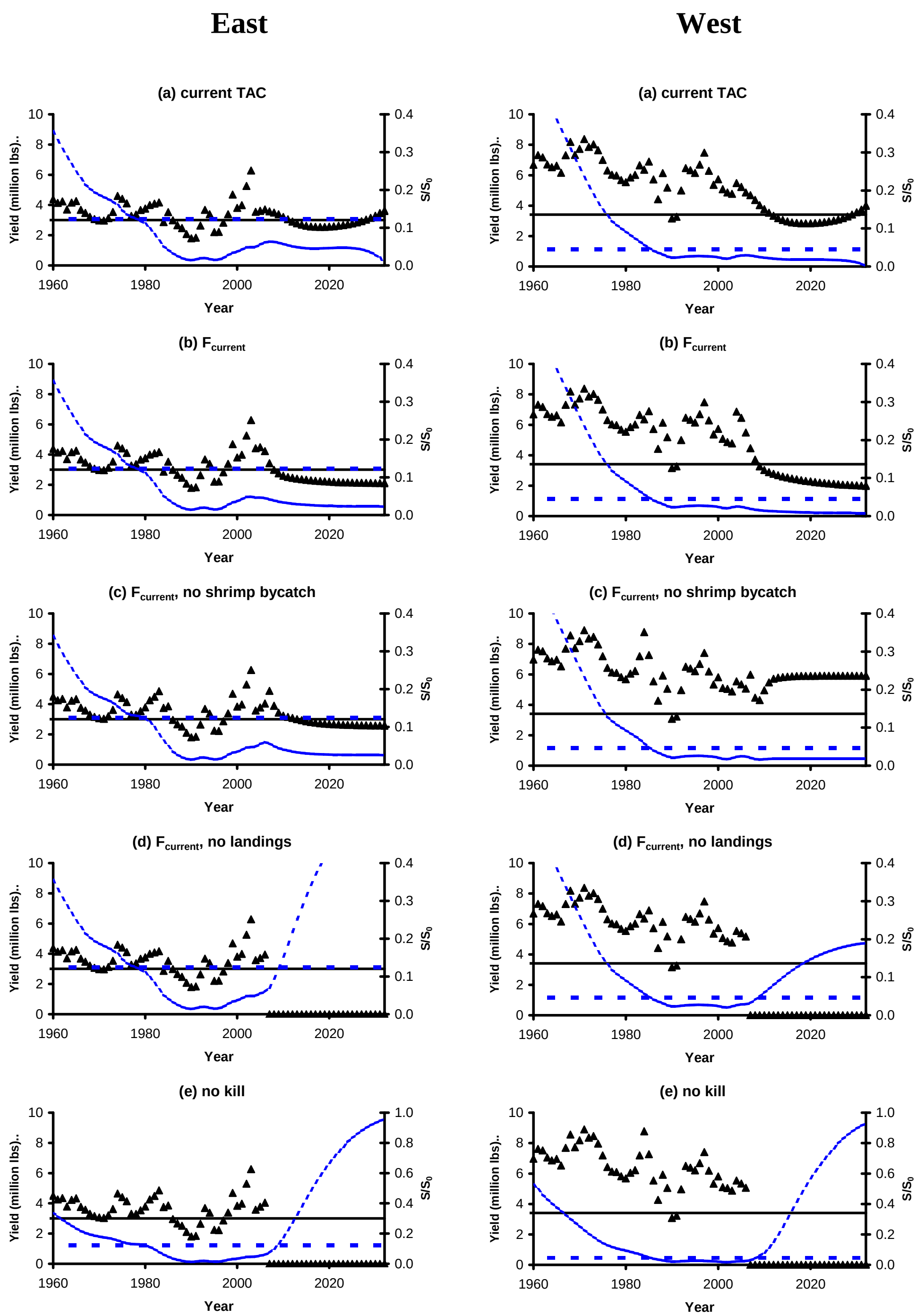

Figure 10 Projected trends in effective number spawners relative to virgin levels (S/S_0, lines lines) and landings (yield in weight, triangles) under (a) the current TAC of 9.12 mp, (b) current *F* levels, (c) current *F* levels except no shrimp bycatch, (d) current *F* levels except no landings and (e) no fishing. Horizontal lines represent MSY (solid) and S_{MSY} (dashed) conditioned on current levels of bycatch (shrimp and closed season).

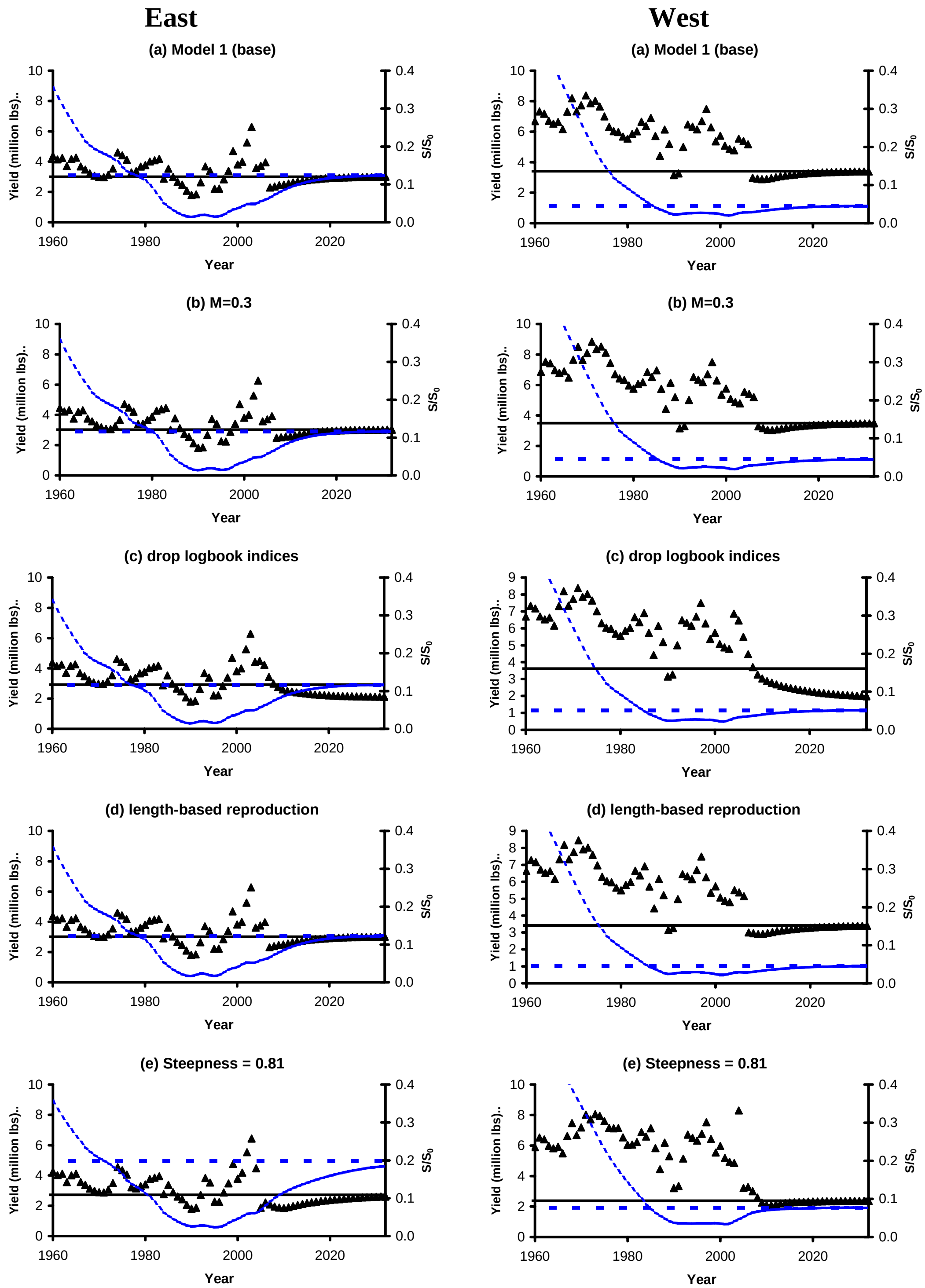

Figure 11. Projected trends in effective number spawners relative to virgin levels (S/S_0, solid lines) and landings (yield in weight, dashed lines) when closed season discards and shrimp effort continue at current rates and the directed fleet fishes at F_{MSY}\{current-shrimp\} assuming (a) model 1, the base model; (b) model 2, where M_1=0.3; (c) model 3, where the handline logbook indices are dropped; (d) model 4, with a length-based reproductive potential curve; and (e) model 5, with steepness fixed to 0.81.

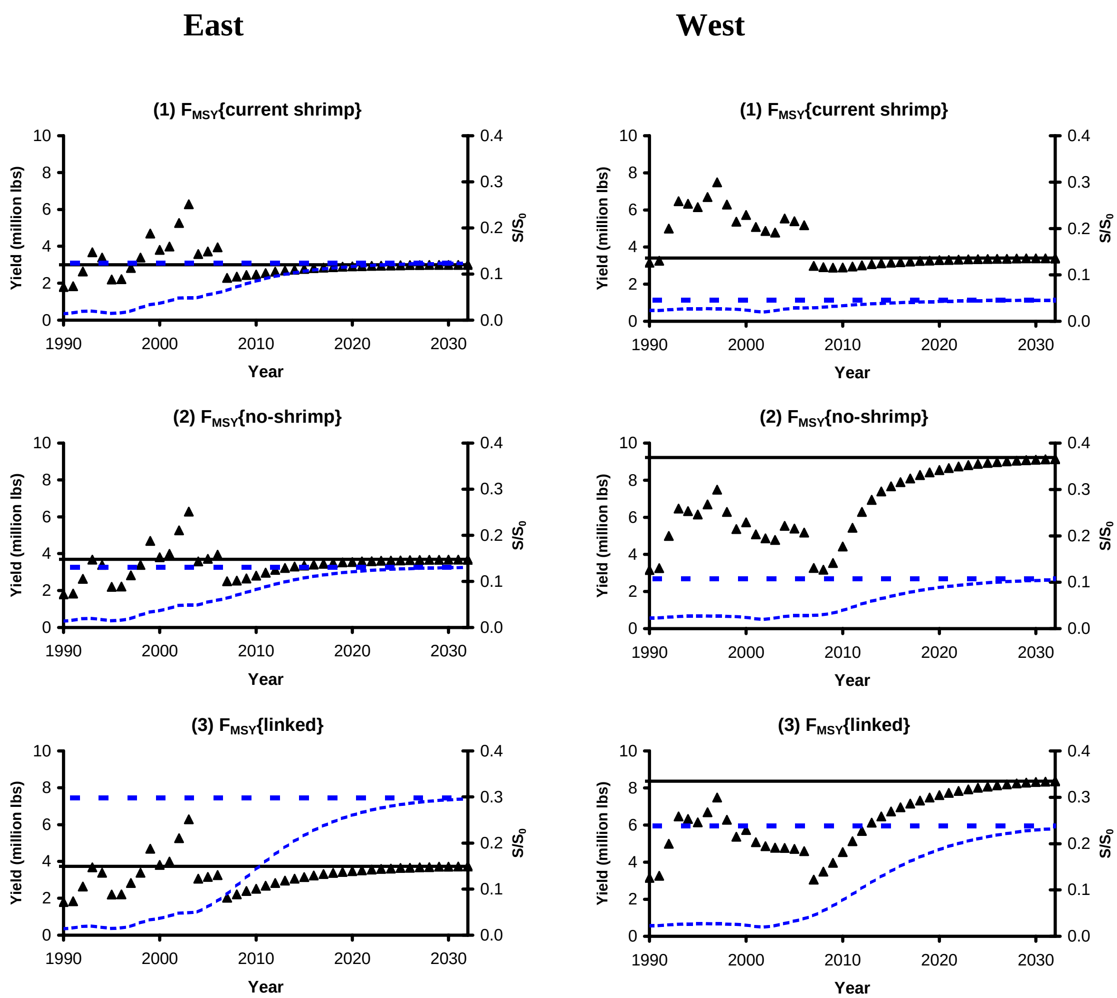

Figure 12a. Projected trends in effective number spawners relative to virgin levels (S/S_0, dashed lines) and landings (yield in weight, solid lines) when the respective fisheries operate according to three different management policies: (1) F_{MSY}{current-shrimp}, where closed-season and shrimp bycatch rates continue at current levels; (2) F_{MSY}{no-shrimp}, where closed-season bycatch continues at current levels and the offshore shrimp fishery is discontinued; and (3) F_{MSY}{linked}, where the reductions in bycatch are commensurate with the reduction in the effort of the directed fleets. Note that the yield statistic includes only the landings of the directed fleet. Horizontal lines represent the values associated with the different definitions of MSY (solid) and S_{MSY} (dashed).

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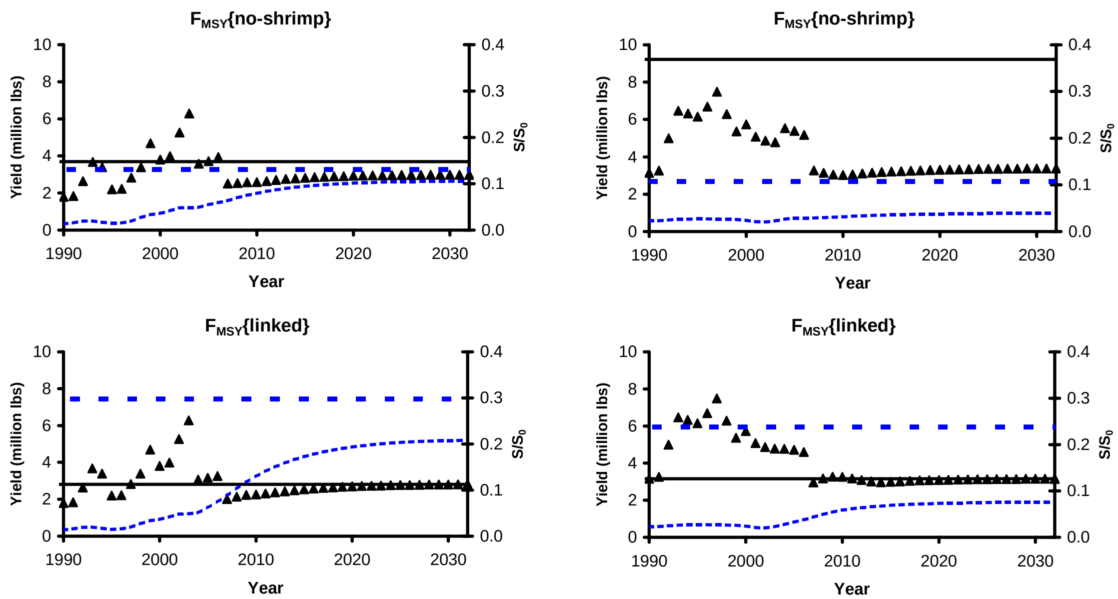

Figure 12b. Projected trends in effective number spawners relative to virgin levels (S/S_0, dashed lines) and landings (yield in weight, solid lines) when the benchmarks are based on MSY{no-shrimp} or MSY{linked} and the directed fisheries operate accordingly (fishing at F_{MSY}{no-shrimp} or F_{MSY}{linked}), but the shrimp bycatch is not reduced. Note that the yield statistic includes only the landings of the directed fleet. Horizontal lines represent the values associated with the different definitions of MSY (solid) and S_{MSY} (dashed).

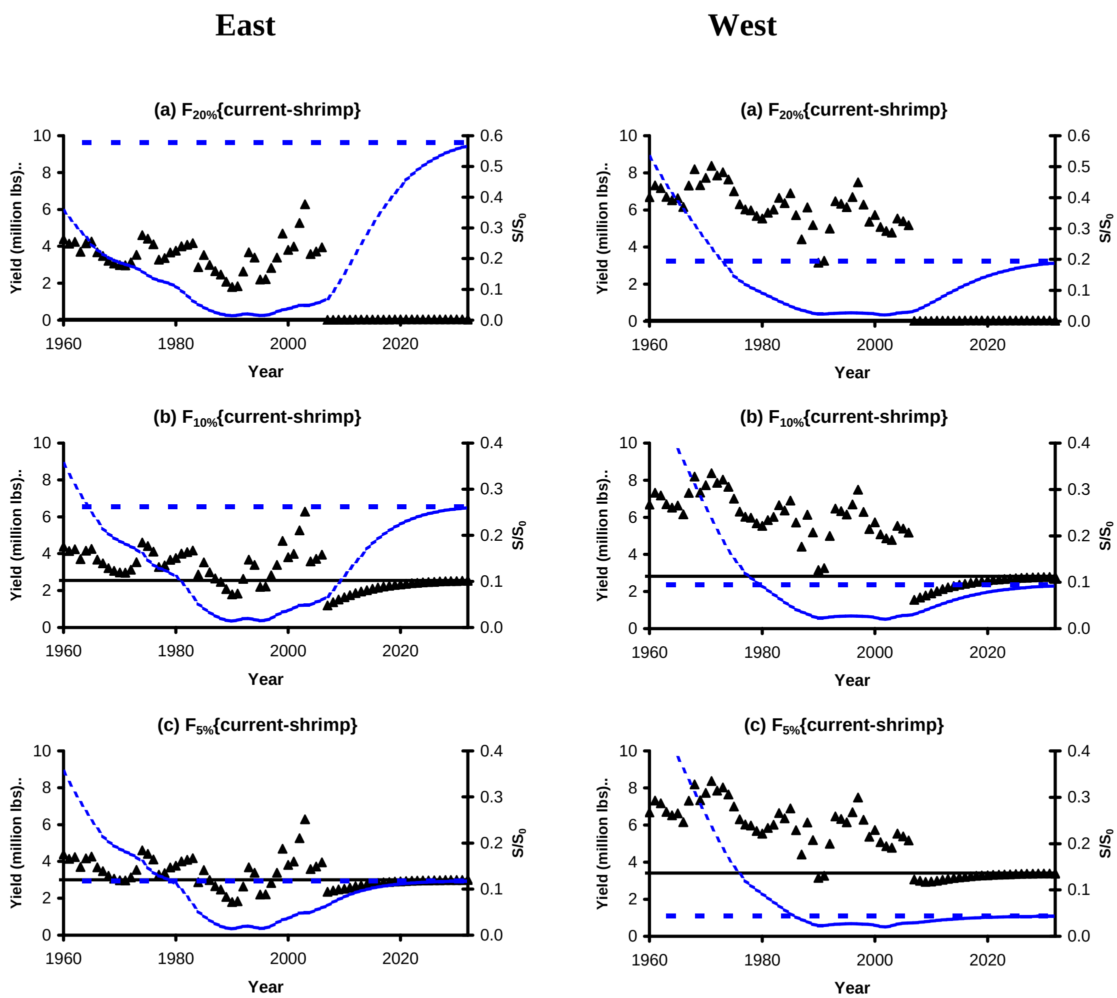

Figure 13. Projected trends in effective number spawners relative to virgin levels (S/S_0, solid lines) and landings (yield in weight, dashed lines) when closed season discards and shrimp effort continue at current rates and the directed fleet fishes at (a) $F_{20\%}${current-shrimp}, (b) $F_{10\%}${current-shrimp}, and (c) $F_{5\%}${current-shrimp}.Horizontal lines represent the long-term yield (solid) and spawning potential (dashed) associated with the given SPR levels. Note that the yield under $F_{20\%}${current-shrimp}is very low (about 9,000 lbs), but $S_{20\%}/S_0$ is high enough to necessitate a scale change.

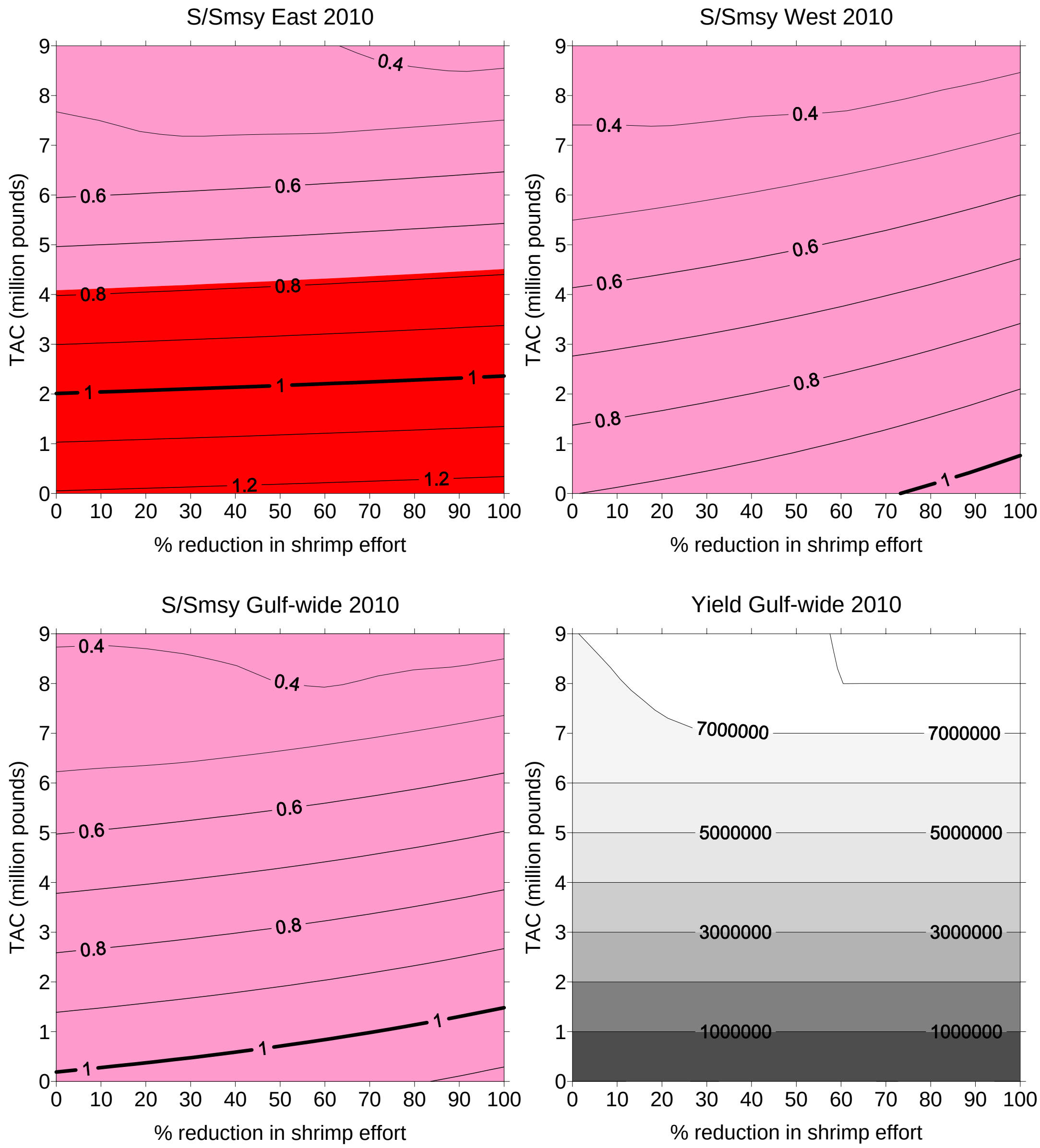

Figure 14a. Isopleths of effective number spawners in the year 2010 relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on an assumed 40 percent reduction in effective offshore shrimp effort. The horizontal axis refers to the projected percent reduction in shrimp effort and the vertical axis refers to the projected Gulfwide TAC (total allowed catch for the directed fishery in millions of pounds). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink shades represent $S/S_0<10\%$ and red shades represent $10\% \leq S/S_0 < 20\%$ (in these cases, stock biomass is not expected to exceed 15% of virgin level). Yield isopleths that do not coincide with the TAC labels (TACs above 6 million lbs) indicate that the higher TAC could not be sustained.

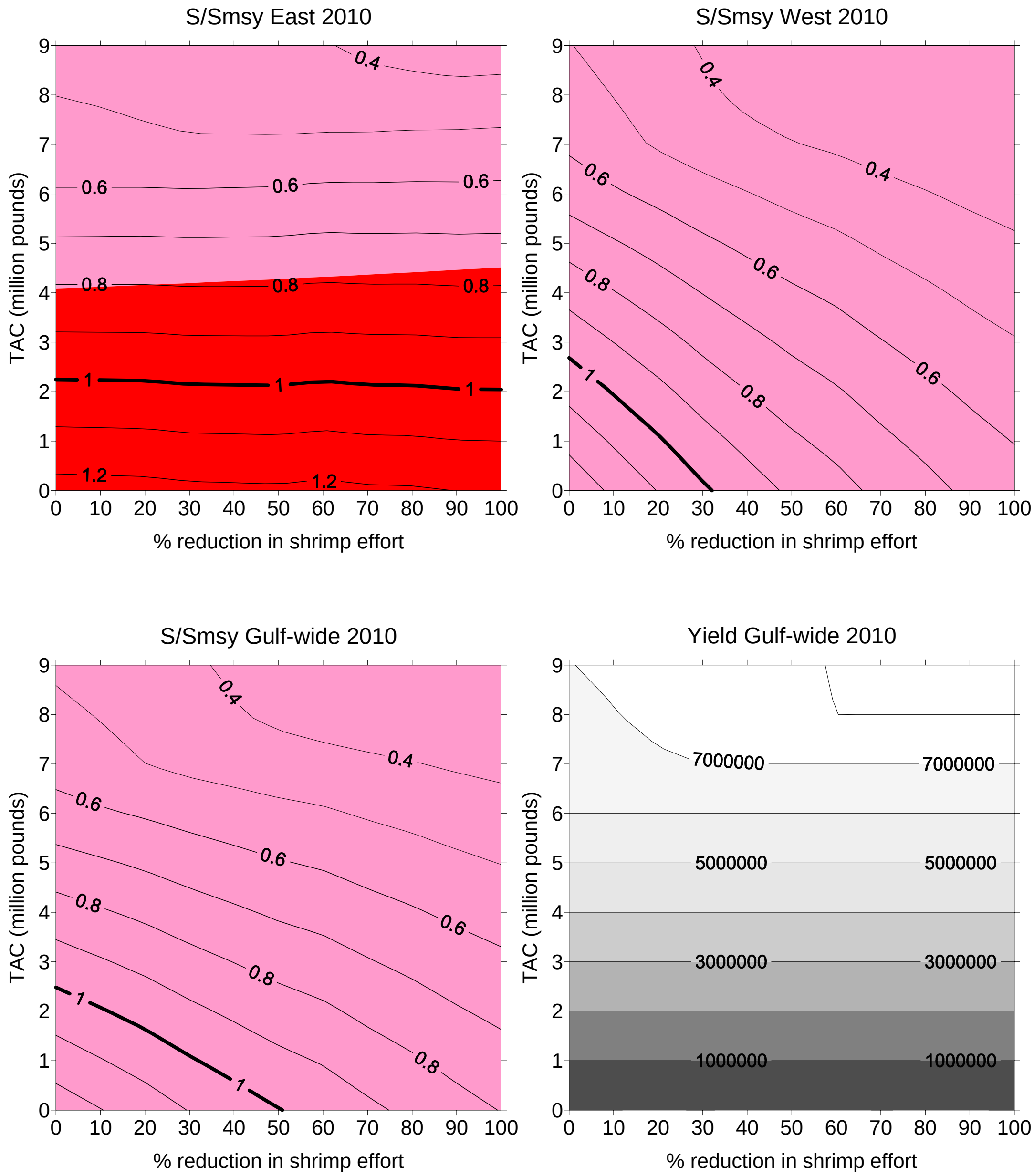

Figure 14b. Isopleths of effective number spawners in the year 2010 relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the projected percent reduction in shrimp effort indicated on the horizontal axis. The vertical axis refers to the projected Gulfwide TAC (total allowed catch for the directed fishery in millions of pounds). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink shades represent $S/S_0<10\%$ and red shades represent $10\%\leq S/S_0<20\%$ (in these cases, stock biomass is not expected to exceed 15% of virgin level). Yield isopleths that do not coincide with the TAC labels (TACs above 6 million lbs) indicate that the higher TAC could not be sustained.

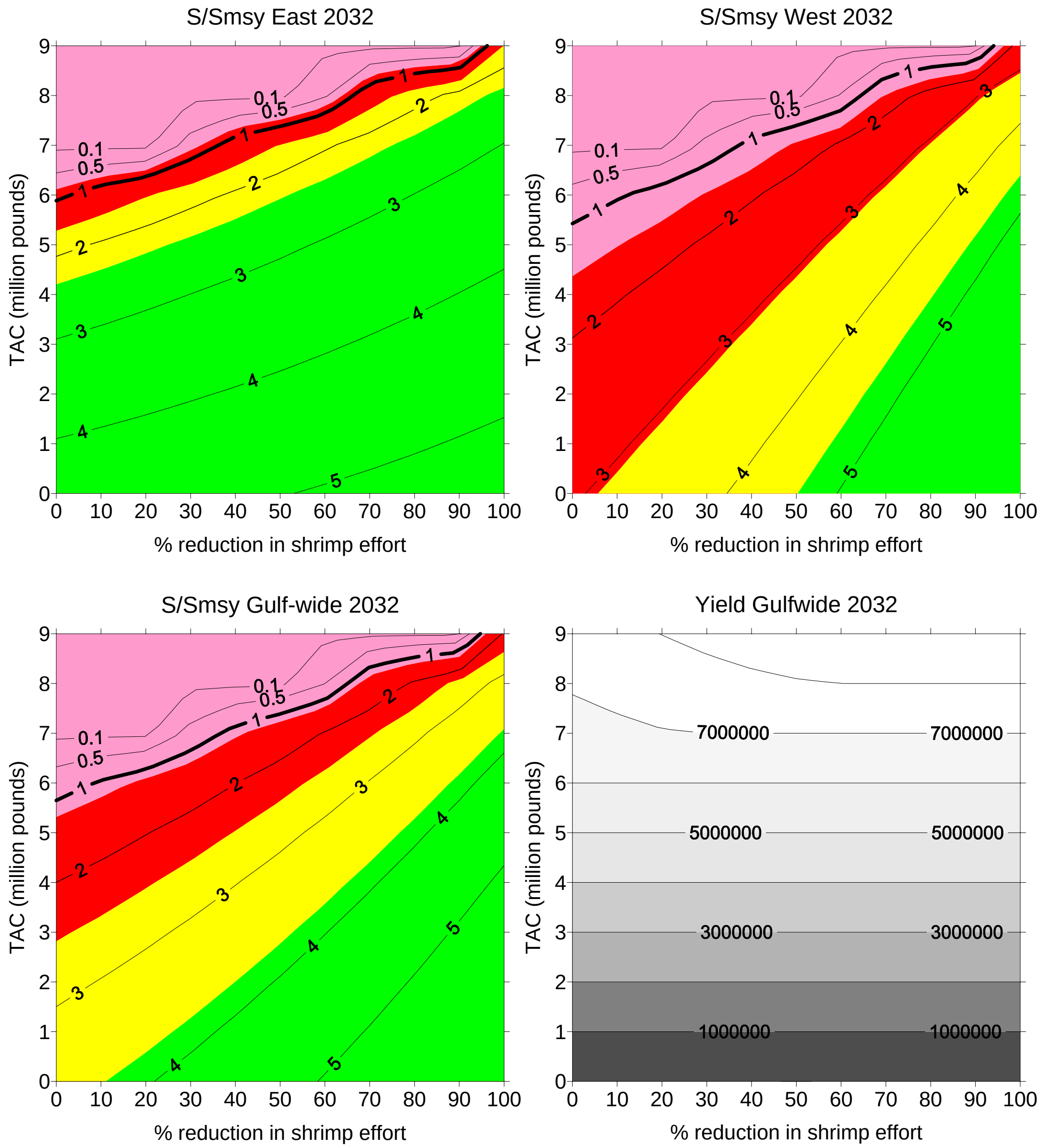

Figure 15a. Isopleths of effective number spawners in the year 2032 relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on an assumed 40 percent reduction in effective offshore shrimp effort. The horizontal axis refers to the projected percent reduction in shrimp effort and the vertical axis refers to the projected Gulfwide TAC (total allowed catch for the directed fishery in millions of pounds). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink represents $S/S_0<10\%$, red $10\%\leq S/S_0<20\%$, yellow $20\%\leq S/S_0<30\%$, and green $S/S_0\geq 30\%$. Yield isopleths that do not coincide with the TAC labels (TACs above 6 million lbs) indicate that the higher TAC could not be sustained.

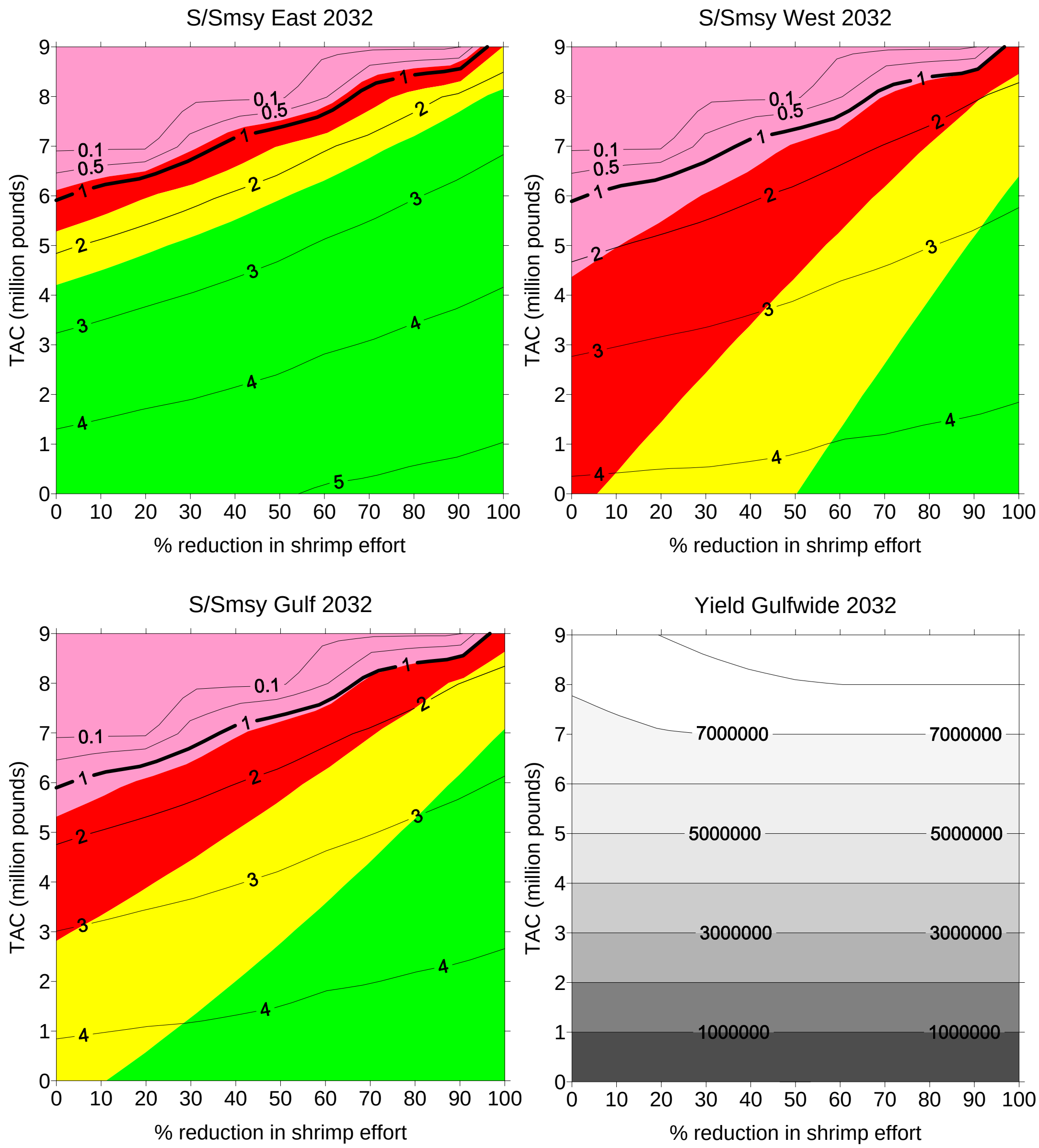

Figure 15b. Isopleths of effective number spawners in the year 2032 relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the projected percent reduction in shrimp effort indicated on the horizontal axis. The vertical axis refers to the projected Gulfwide TAC (total allowed catch for the directed fishery in millions of pounds). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink represents $S/S_0<10\%$, red $10\%\leq S/S_0<20\%$, yellow $20\%\leq S/S_0<30\%$, and green $S/S_0\geq 30\%$. Yield isopleths that do not coincide with the TAC labels (TACs above 6 million lbs) indicate that the higher TAC could not be sustained.

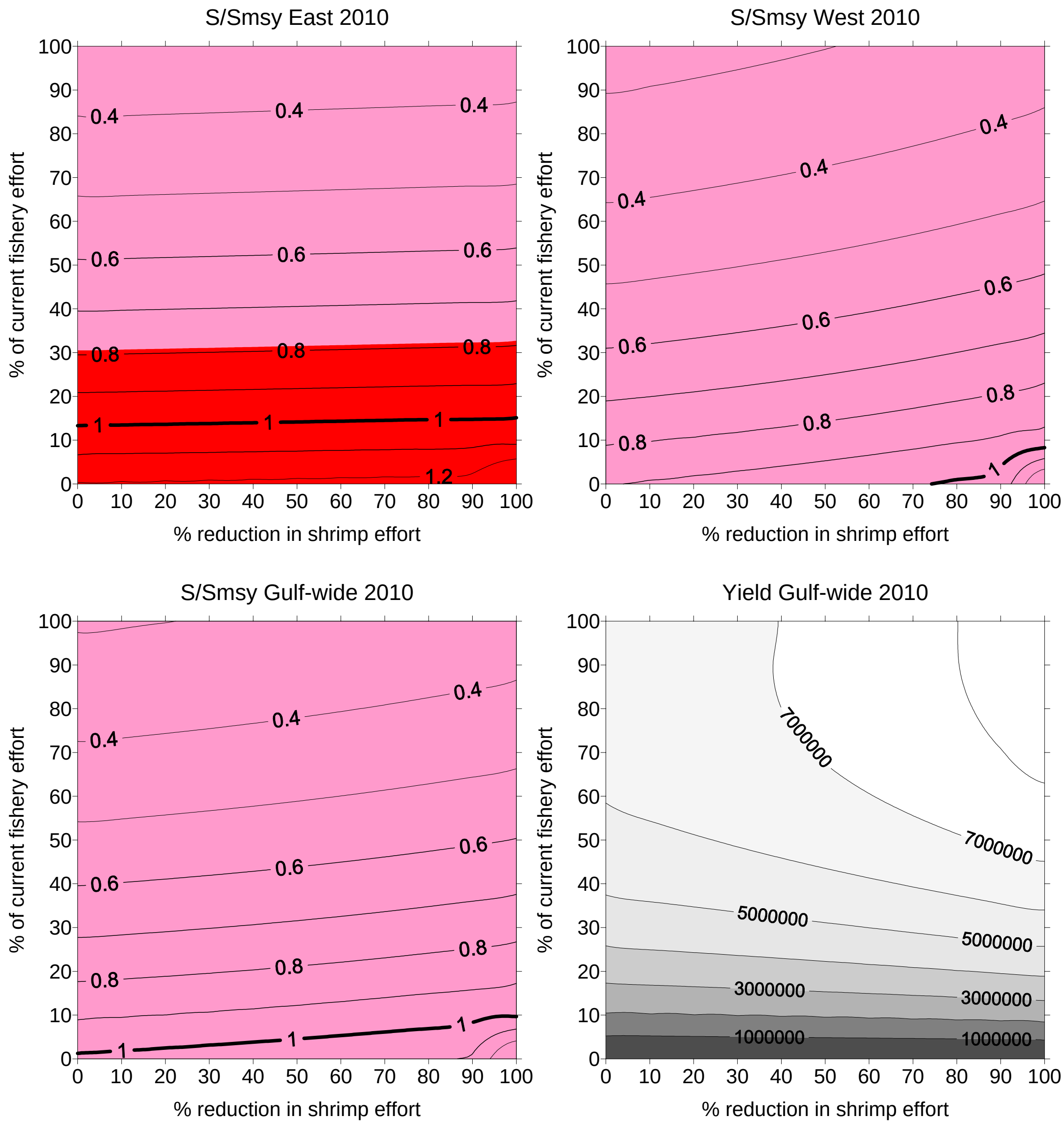

Figure 16a.. Isopleths of effective number spawners in the year 2010 relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on an assumed 40 percent reduction in effective offshore shrimp effort. The horizontal axis refers to the projected percent reduction in shrimp effort and the vertical axis refers to the projected fishing mortality rate of the directed fishery (expressed as a percentage of current levels). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink shades represent $S/S_0<10\%$ and red shades represent $10\%\leq S/S_0<20\%$ (in these cases, stock biomass is not expected to exceed 15% of virgin level.

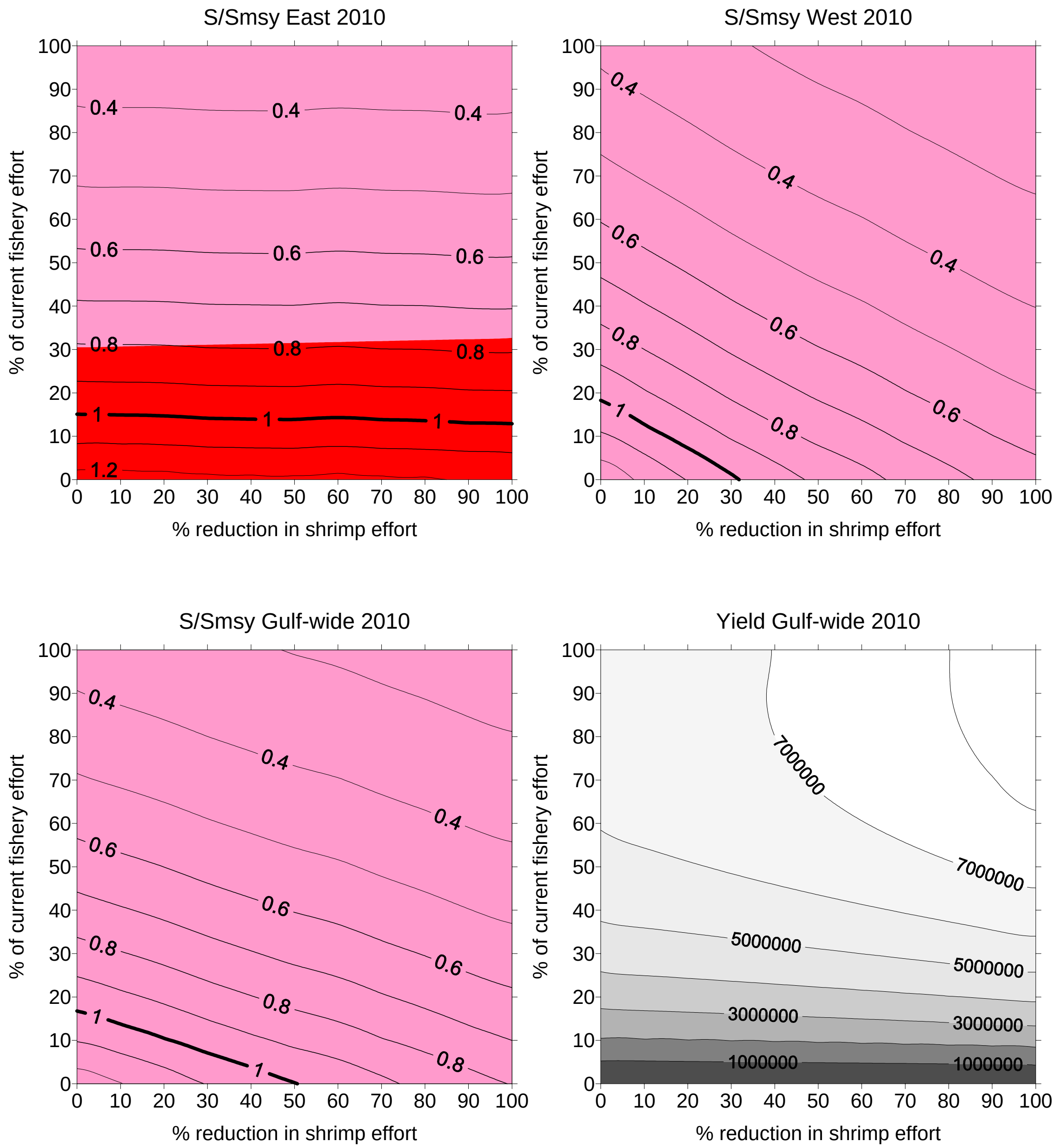

Figure 16b. Isopleths of effective number spawners in the year 2010 relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the projected percent reduction in shrimp effort indicated on the horizontal axis. The vertical axis refers to the projected fishing mortality rate of the directed fishery (expressed as a percentage of current levels). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink shades represent S/S_0<10% and red shades represent 10%≤S/S_0<20% (in these cases, stock biomass is not expected to exceed 15% of virgin level).

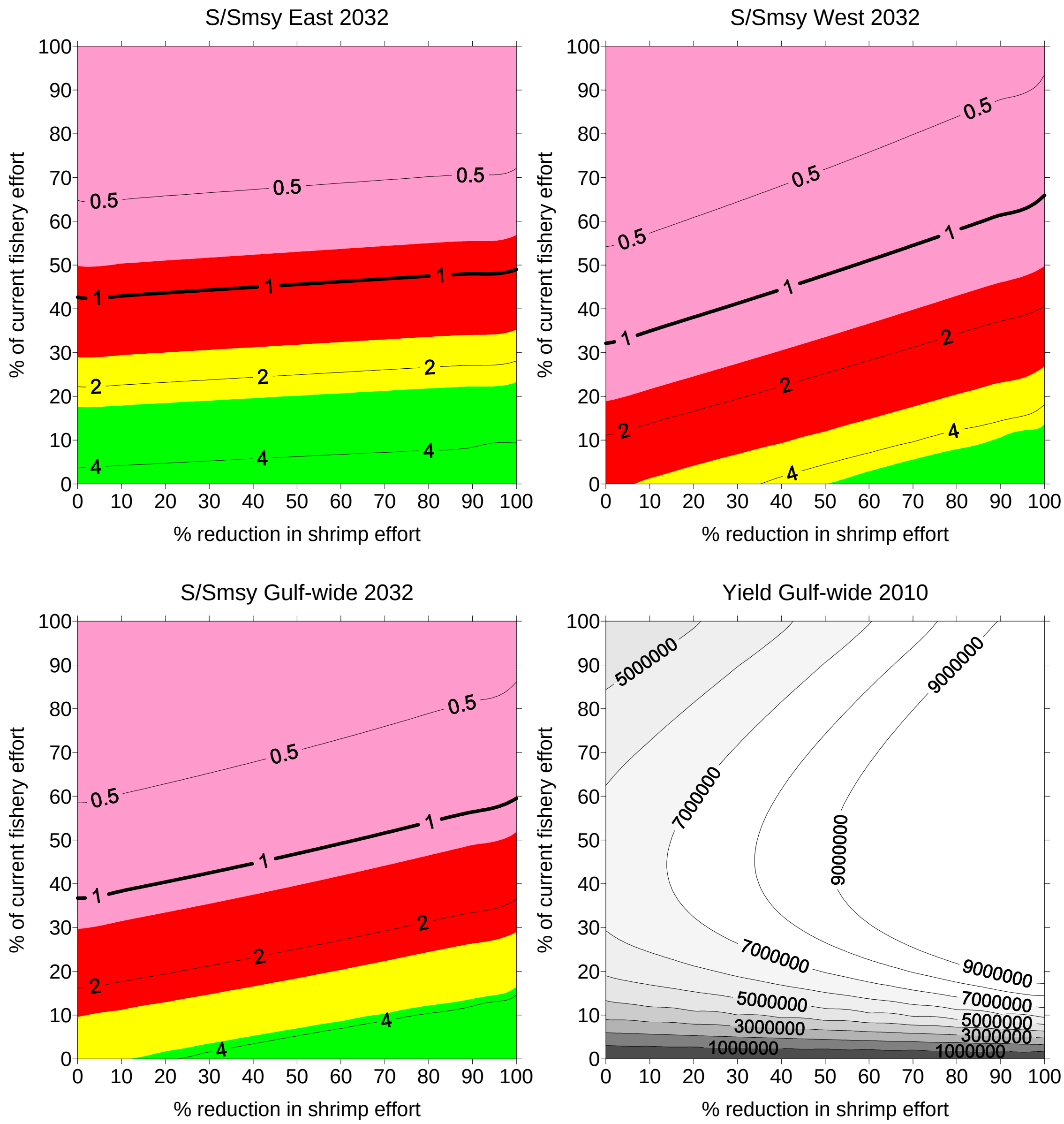

Figure 17a. Isopleths of effective number spawners in the year 2032 relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on an assumed 40 percent reduction in effective offshore shrimp effort. The horizontal axis refers to the projected percent reduction in shrimp effort and the vertical axis refers to the projected fishing mortality rate of the directed fishery (expressed as a percentage of current levels). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink represents $S/S_0<10\%$, red $10\%\leq S/S_0<20\%$, yellow $20\%\leq S/S_0<30\%$, and green $S/S_0\geq 30$

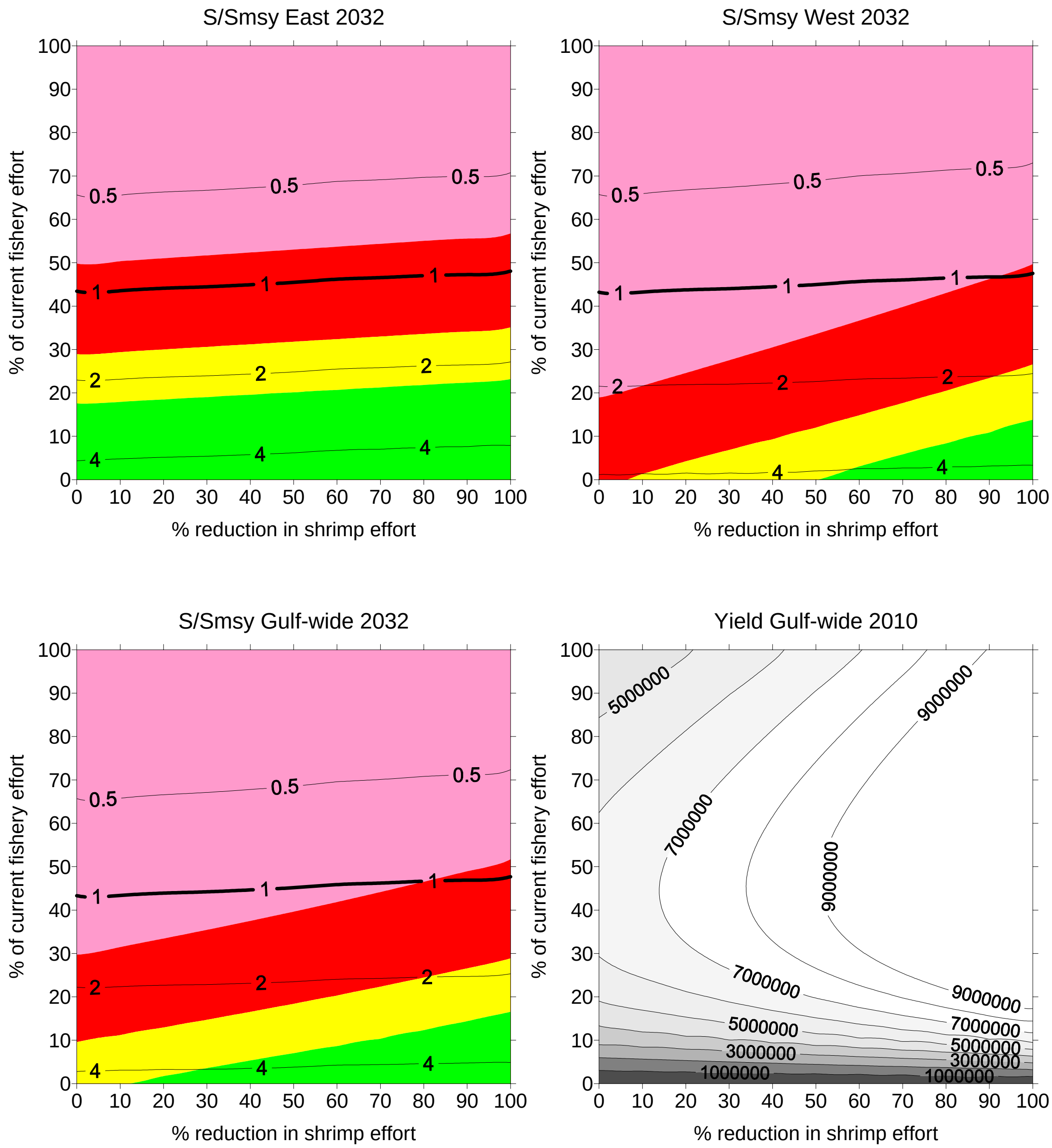

Figure 17b. Isopleths of effective number spawners in the year 2032 relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the projected percent reduction in shrimp effort indicated on the horizontal axis. The vertical axis refers to the projected fishing mortality rate of the directed fishery (expressed as a percentage of current levels). The color shades on the graphs represent different levels of stock biomass relative to virgin conditions: pink represents $S/S_0<10\%$, red $10\%\leq S/S_0<20\%$, yellow $20\%\leq S/S_0<30\%$, and green $S/S_0\geq 30\%$